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Deepwater Shrimp

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On the cover: Deep-water shrimp, *Heterocarpus laevigatus*, from 650 m depth, Kosrae, FSM. Photo by W. B. Saunders.

Articles — *54(1), 1992*

Characteristics of Billfish Anglers in the U.S. Atlantic Ocean — *Mark R. Fisher* and *Robert B. Ditton* **1**

Effects of the Santa Barbara, Calif., Oil Spill on the Apparent Abundance of Pelagic Fishery Resources — *James L. Squire, Jr.* **7**

Remote Camera and Trapping Survey of the Deep-water Shrimps *Heterocarpus laevigatus* and *H. ensifer* and the Geryon Crab *Chaceon granulatus* in Palau — *W. B. Saunders* and *Lee C. Hastie* **15**

On the Distribution and Fishery Potential of the Japanese Red Crab *Chaceon granulatus* in the Palauan Archipelago, Western Caroline Islands — *L. C. Hastie* and *W. B. Saunders* **26**

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Characteristics of Billfish Anglers in the U.S. Atlantic Ocean

MARK R. FISHER and ROBERT B. DITTON

Introduction

A mail survey of U.S. billfish tournament anglers in the western Atlantic Ocean (from Maine to Texas, including Puerto Rico and the U.S. Virgin Islands) was completed to provide a social and economic profile of this group of anglers and to examine their fishing activity, attitudes, trip expenditures, consumer's surplus, catch, and management preferences. The research was initiated in response to social and economic research needs identified in the Atlantic Fishery Management Plan (FMP) for Billfish[1]. Also, better social and economic information was expected to expand constituency support for billfish conservation. Although the number of billfish anglers may be small, their economic effect may be disproportionately high due to greater expenditures per angler per day with a significant impact on local and regional economies. Without adequate conservation measures for billfish, these benefits could be reduced or lost.

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ABSTRACT—A mail survey of 1,984 U.S. billfish tournament anglers was completed to examine their fishing activity, attitudes, trip expenditures, consumer's surplus, catch levels, and management preferences. A sample of 1,984 anglers was drawn from billfish tournaments in the western Atlantic Ocean (from Maine to Texas, including Puerto Rico and the U.S. Virgin Islands) during 1989. A response rate of 61% was obtained (excluding nondeliverables). Anglers averaged 13 billfish trips per year, catching a billfish 40% of the time while 89% of billfish caught were released with <1 billfish per year per angler retained. Catch and retention rates varied by region. Expenditures averaged $1,600 per trip, but varied by region. The annual consumer's surplus was $262 per angler, but increased to $448 per angler if billfish populations were to increase. An estimated 7,915 tournament anglers in the U.S. western Atlantic spent $179,425,000 in pursuit of billfish in 1989. Anglers opposed management options that would diminish their ability to catch a billfish, but supported options limiting the number of billfish landed.

Before August 1988, there was no approved FMP for Atlantic billfishes, although the five Atlantic Fishery Management Councils implemented a Preliminary Management Plan[2] in March 1978 and proposed several draft FMP's from 1976 to 1988. These early plans espoused the idea that billfish were best reserved for recreational purposes because of their historical and traditional use by anglers, the anglers' custom of releasing a large percentage of their catch, and the economic value of the recreational fishery.

By setting minimum length requirements and prohibiting the sale of billfishes, the FMP (50 C.F.R. 644) seeks to conserve 4 species: Sailfish, *Istiophorus platypterus* (57 inches lower jaw fork length); blue marlin, *Makaira nigricans* (86 inches lower jaw fork length); white marlin, *Tetrapturus albidus* (62 inches lower jaw fork length); and longbill spearfish, *Tetrapturus pfluegeri* (no minimum length). Also, there is a prohibition on the possession of these species by longline and driftnet vessels in the Federal fisheries jurisdiction (EEZ). The five councils that approved the FMP sought to prevent a domestic market for billfish with a "no sale" provision. They recognized a directed commercial fishery could result in a substantial harvest if there was an incentive to catch billfish[1]. Also, the prohibition of the sale of incidentally caught billfish set a precedent because it reserved billfish for the recreational fishery.

The billfish FMP[1] was heavily predicated on social and economic considerations[3]. Typically, the optimum yield of a fishery (OY) is defined as ". . . that amount of fish which will provide the greatest overall benefit to the Nation, with particular reference to food production and recreational opportunities; and which is prescribed as such on the basis of the maximum sustainable yield from such fishery, as modified by any relevant economic, social, or ecological factor" (16 U.S.C. 1802). Because of limited biological data, MSY for billfish could not be determined. Optimum yield, however, does not have to be expressed numerically when MSY is unreliable or inestimable (50 C.F.R. 602.11). Therefore, the councils defined OY as "the greatest number of billfish that can be caught by the recreational fishery in the EEZ"[1].

[1]Fishery management plan, final environmental impact statement, regulatory impact review, and initial regulatory flexibility analysis for Atlantic billfishes. 1988. S. Atl. Fish. Manage. Counc., Southpark Bldg., Suite 306, 1 Southpark Circle, Charleston, SC 29407

[2]Preliminary management plan for Atlantic billfishes and sharks. 1978. S. Atl. Fish. Manage. Counc., Southpark Bldg., Suite 306, 1 Southpark Circle, Charleston, SC 29407.

[3]Source document for the fishery management plan for the Atlantic billfishes. 1988. S. Atl. Fish. Manage. Counc., Southpark Bldg., Suite 306, 1 Southpark Circle, Charleston, SC 29407.

The rationale of the FMP was to optimize the social and economic benefits to the nation by reserving the resource for the traditional recreational fishery.

Little quantitative data was included in the FMP regarding social and economic benefits of the recreational billfish fishery for several reasons. First, since billfish anglers account for a small part of the total population of saltwater anglers, state and Federal fishery surveys did not intercept many billfish anglers (Fedler and Ditton, 1988). Consequently, total billfish participants, trips, expenditures, and harvest were difficult to estimate accurately. Second, because irregularly implemented surveys have been used to gather information on this "rare event" fishery, results were either not applicable over the entire range of the fishery (Figley, 1984; Freeman, 1985; Brown and Ofiera, 1987) or were outdated (Hamm and Slater, 1979).

The economic value of the recreational billfish fishery was not adequately discussed in the FMP. Expenditures, which are the usual measure of the value of a recreational fishing trip and are essential to understand local economic impacts, are not a valid measure of the trip's true economic worth. Expenditures do not represent an addition to the welfare of the nation because they would probably be spent for something else if not for billfish (Huppert, 1983). Furthermore, a fishing trip has much greater value than the costs associated with getting to, using, and returning from the resource. Testing one's skills, experiencing adventure, relaxing, camaraderie with friends and family are some of the other components of a fishing trip which are also of value to an angler. Estimating the value of these benefits (consumer's surplus) can be ascertained using contingent valuation methods (CVM) which measure willingness to pay in excess of trip expenditures (Huppert, 1983). Consumer's surplus is an important concept because it represents an increase in the welfare of the nation as a result of the opportunity to fish for billfish.

In light of the limited social and economic information contained in the Billfish FMP, this paper has three objectives: 1) To profile the population of billfish tournament anglers according to their social and economic characteristics and to examine their fishing activity, attitudes, trip expenditures, consumer's surplus, catch levels, and management preferences; 2) to estimate the anglers' total catch, trip expenditures, and consumer's surplus in the study area; and 3) to discuss the implications of angler attitudes regarding present and future billfish management measures.

Methods

A survey of billfish anglers is difficult because the population of billfish anglers is not readily identifiable. No special license exists that can provide a list of billfish anglers. Therefore, we sampled from a list of U.S. anglers who had participated in billfish tournaments during 1989. This proxy group was identifiable and provided a cost-effective means of obtaining information from billfish anglers.

We completed an inventory of 359 billfish tournaments held during 1989 in the study area (Maine to Texas, including Puerto Rico and U.S. Virgin Islands). Tournaments were located in every coastal Atlantic or Gulf state except Connecticut, Mississippi, and New Hampshire. Tournaments in the Bahamas with a U.S. mailing address or telephone number were included with the assumption most entrants were U.S. citizens.

A sampling goal of 2,000 billfish anglers was based solely on cost considerations since population size and variance were unknown. A sample size of 380 was considered sufficient to represent a large population (Krejcie and Morgan, 1970), but a larger sample was required to test for group differences.

Twenty-seven tournaments could provide a total sample of 2,000 if each tournament provided names and addresses of 75 billfish anglers. Tournaments were sorted in chronological order and a random sample of 27 was selected. Tournament directors were contacted in August 1989 to explain the purpose of the survey and to solicit their cooperation. Those who refused to participate were replaced with another randomly selected tournament.

A total of 1,984 billfish anglers was selected. Officials from selected tournaments were asked to provide a list of participants. A systematic sample of 75 was selected from tournaments with >75 participants while all were selected from smaller tournaments ($\leq$75 participants). Only those anglers listing a U.S. address were considered for sampling.

A 10-page questionnaire was developed to collect information from anglers. First, anglers were asked about their fishing experience: Number of years fishing, number of years fishing for billfish, number of days in the previous 12 months by setting, and an evaluation of their fishing ability compared with other anglers. Second, they were asked to identify their top three target species and to indicate whether any one species commanded most of their effort. Third, anglers were asked to evaluate several management options and if implementation would cause them to stop fishing for billfish. Anglers were also asked if they were familiar with the new minimum size limits and if their fishing was affected. Fourth, we asked anglers a series of questions to identify characteristics of a typical trip and their most recent billfish tournament (effort, species targeted, and catch/retention rates). Fifth, anglers were asked to report how much they spent for each of 11 expense items on their most recent billfishing trip.

We used two closed-ended contingent valuation (CVM) questions to ascertain the amount anglers were willing to pay for a billfish stamp at current billfish population levels, and at a 25% increase in the billfish population. Each angler was presented noniteratively with a random offer from a preselected range of eight bid values from $25 to $200. Consumer's surplus was evaluated using logistic regression. Logistic regression is appropriate when the dependent variable is a binary indicator variable (e.g., "yes" or "no"), and can be used to determine the threshold level of an angler's willingness-to-pay (Agresti, 1990).

Using data provided by the angler sample, we estimated the total number of tournament billfish anglers in the study area. From this, we estimated to-

tal annual expenditures, consumer's surplus, and billfish catch and landings by extrapolation of sample results.

A total of 1,171 individuals responded to the mail survey for an overall response rate of 61.4% (when nondeliverables were excluded). Mailings were initiated on 27 October 1989 following the procedures of Dillman (1978). Since some tournaments in the sample had not taken place or provided their list of participants, questionnaires were mailed on 27 October to a partial sample of 966 billfish anglers to minimize their recall time. A reminder postcard was mailed on 3 November, with second and third mailings on 20 November and 9 January, respectively. Surveys were mailed to the remaining 1,018 anglers on 19 February 1990, following the same procedures and time sequence.

A telephone survey of nonrespondents was completed to identify characteristics of nonrespondents for comparison with respondents. This was done to test the assumption that the two groups were alike for making projections of harvest and expenditures (Bethlehem and Kersten, 1985). Questions were used regarding years of saltwater fishing experience, species preference, years of billfishing experience, and annual frequency of participation. Telephone calling resulted in 77 completed surveys from a sample of 190 nonrespondents. Using the Mann-Whitney U or chi-square test, as appropriate, we found no significant differences between respondents and nonrespondents at the 0.05 level of significance. Therefore, our use of respondents' expenditure and harvest level data for nonrespondents in making projections was validated.

Results

Angler Characteristics

Thirty-six states (including Puerto Rico, the U.S. Virgin Islands, and the District of Columbia) were represented in the sample of billfish tournament anglers. Over 93% resided in coastal states or jurisdictions. Most (58%) anglers reported fishing 21 years ($\bar{X}$=26 years). When compared with age distribution data, a lifetime commitment to saltwater fishing is suggested. Most (52%) reported fishing for billfish ≥11 years ($\bar{X}$=14 years). When compared with the mean for saltwater fishing, it can be argued most began fishing for billfish after several years of saltwater experience. Most (70%) reported they did not fish in freshwater or from the shore in saltwater during the previous 12 months. In contrast, 83% reported they fished at least 14 days in saltwater from a boat ($\bar{X}$=39 days). In total, the sample of anglers spent an average of 44 days fishing in the previous 12 months. About 37% rated themselves as "more skilled" than other anglers. Almost 93% rated themselves as "equally or more skilled" with the remainder "less skilled."

Species Preferences

Species from the billfish family (Istiophoridae) were most preferred (first choice) by 71% of the respondents. Blue marlin was the most preferred single species (39%). Also, istiophorids were most preferred as a second and third choice by 46% and 28% of the respondents, respectively. White marlin was the second-most preferred single species (17%) followed by sailfish (15%). Over 90% of the respondents listed pelagic species only, and 62% reported they devoted most of their effort to one species. Of this group, istiophorids were targeted by 73% with blue marlin the most sought single species (29%).

Angler Opinions on Fisheries Management Options

Most billfish anglers were opposed to reducing the minimum sizes for billfish in the FMP, no minimum sizes for tournament-caught fish, no minimum sizes for fish to be mounted by a taxidermist, banning double hooks, allowing handlining or harpooning for recreational purposes, banning "live baiting," a one billfish per boat per day bag limit, and area closures for the fishery (Table 1). Most supported larger minimum sizes for billfish, larger minimum sizes for tournament-caught fish, mandatory "no kill" tournaments, a one billfish per angler per day bag limit, a zero bag limit, and a billfish stamp. Anglers were evenly divided over banning stainless steel hooks and seasonal closures for the fishery.

Several alternate billfish regulations were so unfavorable to some anglers they reported they would stop fishing if they were implemented. Area closures would cause the greatest exit from the fishery (12% of respondents), followed by seasonal closures (11%), a billfish stamp (10%), zero bag limit (10%), one billfish per boat per day bag limit (10%), and allowing harpooning and handlining for recreational purposes (8%). The strength of opposition to these regulations (except har-

Table 1.—Distribution of billfish anglers by the extent they support/oppose management options for billfish; ranked by mean score.

	Percent by category[1]						
Management option	1	2	3	4	5	Mean	*n*
Increased minimum sizes for tournaments	7.8%	12.1%	18.8%	29.2%	32.1%	3.66	1,060
Increased minimum sizes	6.2	13.6	20.1	29.8	30.2	3.64	1,072
Zero bag limit	11.0	14.7	16.3	24.1	33.8	3.56	1,077
Mandatory "no kill" tournaments	9.3	17.0	19.7	21.3	32.8	3.51	1,077
1 billfish/angler/day	15.9	15.0	14.1	27.4	27.6	3.36	1,065
Billfish stamp	14.4	11.0	25.8	28.7	20.1	3.29	1,080
No stainless steel hooks	15.5	18.7	27.7	18.8	19.4	3.08	1,074
Seasonal closures	21.0	20.5	21.5	21.3	15.7	2.90	1,066
Area closures	21.7	21.0	24.3	19.8	13.2	2.82	1,058
1 billfish/boat/day	23.1	26.8	18.8	14.0	17.3	2.76	1,058
No "live baiting"	19.7	28.4	29.2	11.4	11.2	2.66	1,069
No double hooks	24.0	29.7	29.9	8.2	8.2	2.47	1,073
No min. sizes for taxidermy mounts	44.7	23.8	15.0	9.5	7.0	2.10	1,049
No min. sizes for nontournament fish	48.3	29.6	14.0	5.1	3.1	1.85	1,042
Decreased minimum sizes	47.9	28.4	17.9	2.5	3.3	1.85	1,050
Handling/harpooning for recreation	62.4	23.4	8.4	2.0	3.8	1.61	1,049

[1]1=Strongly disagree, 2=Disagree, 3=Neutral, 4=Agree, 5=Strongly agree

pooning and handlining) is not reflected in Table 1. Anglers who reported they would stop fishing were evenly distributed in the study area; opposition was not concentrated in any one region.

Most anglers (81%) reported the minimum size limits implemented in 1989 had no effect on their billfishing activity. Of the 9% reporting they were unfamiliar with the size limits, 46% were from states north of Virginia and 37% from Florida. Finally, most (77%) respondents reported a limit of one billfish per boat per day would have no effect on their fishing behavior, while 23% reported there would be a negative effect if implemented.

Typical Billfish Fishing Trips

Anglers reported an average of 13 billfish trips per year. With each trip lasting about 2.7 days, this resulted in an average of 35 days per year. Each day averaged 8.0 hours of fishing. Effort required to catch a billfish was 6.3 days. Almost 300 respondents (26%) reported they did not catch a billfish in the previous 12 months. These anglers probably did not invest enough time to be successful, as 22% of the respondents made <3 trips in the previous 12 months. On average, each angler landed <1 (0.7) billfish per year, or 1 billfish every 1.4 years. This should be viewed with caution, however, as 71% reported they did not keep any billfish in the past 12 months. Thus, 29% of the billfish angler population accounted for 100% of the fishing mortality.

Trip characteristics (trips per year, trips to catch a billfish, and billfish retained) varied by region (Table 2). The average number of billfish trips per year varied from 8.7 for Gulf of Mexico anglers to 17.3 for Caribbean anglers. Accordingly, the average number of successful trips (trips with billfish caught) varied from 2.4 for Gulf anglers and 7.0 for Caribbean anglers. The success rate was lowest for Gulf anglers (28%) and highest for Mid-Atlantic anglers (46%). The retention rate varied from a mean of 0.35 billfish per angler per year in the Mid-Atlantic to 2.87 in the Caribbean.

Most Recent Billfish Tournament

Anglers reported fishing an average of 2.7 days during their last tournament with an average of 8.3 hours of fishing per day. Blue marlin was the most commonly targeted billfish species (74%), followed by white marlin (49%) and sailfish (43%). While 73% of the respondents did not catch a blue marlin during the most recent tournament, the other 27% (307 anglers) caught a total of 607. Of these, 490 blue marlin were released (81%) with the remainder (117) landed. Similarly, 79% and 82% of the respondents did not catch a white marlin or sailfish, respectively. Nevertheless, 522 white marlin and 687 sailfish were caught. Almost all white marlin and sailfish were released, with only 48 (9%) and 29 (4%), respectively, landed. Two of five spearfish caught were released. In all, 1,129 anglers caught 1,821 billfish but landed only 11% during their most recent tournaments. Of the 1,625 billfish reported as released, 69% were tagged.

Results from Table 2 and Table 3 showed Mid-Atlantic anglers were most successful and released the most billfish. Gulf of Mexico anglers made the fewest trips per year and were the least successful. Caribbean anglers made the most trips per year and landed the most billfish. It would be unwise to provide an estimate for New England based on the results of only 17 respondents, but trip characteristics were comparable to the other Atlantic regions.

Catch and retention rates varied by region (Table 3). Mid-Atlantic anglers caught the most billfish per angler and had the highest release rate per angler. Gulf of Mexico anglers caught the fewest billfish per angler, and Caribbean anglers had the lowest release rate per angler.

Expenditures of Billfish Anglers

On their most recent fishing trip for billfish, respondents reported an average expenditure of $1,601 (excluding tournament fees) (Table 4). The trip averaged 2.59 days in length, with an average expenditure of $618 per day. Boat operation costs (fuel, fresh water, etc.) on billfish trips were highest, and food, drinks, and ice costs were incurred most frequently. The average amount spent annually on billfish tournament fees was $1,856, or $546 per tournament. Since the average number of days spent per tournament (2.66 days) was comparable to the mean number of days on their most recent trip (2.59), total expenditures per angler per tournament was estimated at $1,601 + $546 = $2,147.

Table 2.—Regional billfishing trip characteristics in the western U.S. Atlantic Ocean.

Region[1]	*n*[2]	Trips per year per angler	Successful trips per year per angler[3]	Success rate (%)	Billfish landed per year per angler
Caribbean	100[4]	17.3	6.98	40	2.87
Gulf	326	8.7	2.44	28	0.44
Mid-Atlantic	318	13.0	5.98	46	0.35
South Atlantic	343	16.5	6.72	41	0.66
Total[5]	1,129	13.1	5.21	40	0.68

[1]Only 17 respondents were from New England and are not reported.
[2]Only respondents from coastal states (including Pennsylvania) were distributed by regions.
[3]Trips with billfish caught.
[4]95 respondents were from Puerto Rico.
[5]Includes New England and noncoastal respondents.

Table 3.—Catch and retention rate from most recent tournament by region.

Region	*n*	Total billfish caught	Total billfish landed	Percent release	Catch per angler	Billfish landed per angler
Caribbean	100	184	48	74	1.84	0.48
Gulf	326	270	50	81	0.83	0.15
Mid-Atlantic	318	687	34	95	2.16	0.11
South Atlantic	343	583	51	91	1.70	0.15
Total[1]	1,129	1,821	196	89	1.61	0.17

[1]Includes New England and noncoastal respondents.

Billfishing expenditures (total expenditure per trip, days fishing per trip, and cost per day) varied by region (Table 5). The Caribbean region had the least expensive trips, on a per day and per trip basis. Although the most expensive trips were in the South Atlantic, it was more expensive per day in the Gulf of Mexico. New England mean expenditures were comparable to the other Atlantic regions.

Tables 6 and 7 report the results of the logistic regression model of the willingness-to-pay responses and consumer's surplus estimates. Angler characteristics that were expected to affect willingness-to-pay included 1) annual number of billfish trips, 2) years of fishing experience for billfish, 3) expenditures per billfish trip, and 4) annual household income. Years of fishing experience for billfish was statistically insignificant (P>0.6) and was not included in the final model. The standardized estimates indicate the probability of a "yes" response decreases as the stamp price increases, and increases as income, trip expenditures, and the number of trips/year increases. The number of billfish trips/year appears to have the greatest influence on willingness-to-pay. We also asked anglers the highest price they would pay for a stamp (open-ended) rather than stop fishing for billfish at the current population levels. The average price was $247, indicating good agreement with the logistic model. There were no significant regional differences in mean willingness-to-pay for a billfish stamp.

Table 4.—Mean expenditures from most recent billfish trip in the U.S. western Atlantic Ocean.

Expenditure item	Mean spent per angler	Percent of anglers who bought each item	Mean expense to anglers who bought each item
Food, drinks, ice	$152.61	80.2	$190.29
Boat operation	$462.56	72.8	$635.38
Bait and tackle	$95.65	67.1	$142.55
Automobile transportation	$38.29	58.7	$65.23
Lodging	$163.88	32.9	$498.12
Other transportation[1]	$170.64	25.2	$677.14
Captain/charter fees	$203.75	23.8	$856.09
Other[2]	$90.28	14.1	$640.28
Boat rental	$144.23	10.5	$1,373.62
Entrance fees	$50.57	10.1	$500.69
Boat launch hoist fees	$28.16	8.9	$316.14
Total (n=1129)	$1,600.62		

[1]Includes modes of transportation other than automobiles.
[2]Includes slip rental, repairs, satellite data, and other miscellaneous items.

Table 5.—Mean expenditure per billfishing trip, days fishing per trip, and expenditures per day, by region.

Region	n	Expenditure per trip	Days fishing per trip	Expenditure per day
Caribbean	100	$824	2.13	$387
Gulf	326	$1,232	2.18	$565
Mid-Atlantic	318	$1,454	2.72	$535
South Atlantic	343	$1,905	4.33	$440
Total[1]	1,129	$1,601	2.59	$618

[1]Includes New England and noncoastal respondents.

Table 6.—Logistic regression model of willingness-to-pay for a billfish stamp at current billfish population levels, and consumer's surplus.

Variable description	Parameter estimate and standard error	Wald chi-square value	Prob.> chi-square	Standardized est.
Intercept[1]	0.4006 (0.2576)	2.42	0.1200	
Stamp price	–0.00664 (0.00138)	23.23	0.0001	–0.208
Billfish trips/year	0.0305 (0.0069)	19.39	0.0001	0.307
Total $/trip	0.000137 (0.000052)	6.94	0.0084	0.187
Annual household income	9.76×10^{-6} (2.01×10^{-6})	23.59	0.0001	0.207
n	1,002			
Model chi-square	104.3 (P<0.0001)			
% concordance	70.6			
Consumer's surplus[2]	$262.38			

[1]Nonsignificant and not included in the consumer's surplus calculation.
[2]Calculated using a mean of 13 billfish trips/year, $1,601/trip, and a median household income of $115,000.

Table 7.—Logistic regression model of willingness-to-pay for a billfish stamp at 25% higher billfish population levels, and consumer's surplus.

Variable description	Parameter estimate and standard error	Wald chi-square value	Prob.> chi-square	Standardized est.
Intercept	0.6347 (0.2934)	4.68	0.0305	
Stamp price	–0.00603 (0.00158)	14.58	0.0001	–0.189
Billfish trips/year	0.0436 (0.0097)	20.39	0.0001	0.426
Total $/trip	0.000143 (0.000065)	4.83	0.0280	0.195
Annual household income	1.10×10^{-5} (2.30×10^{-6})	22.09	0.0001	0.229
n	988			
Model chi-square	92.7 (P<0.0001)			
% concordance	72.0			
Consumer's surplus	$447.73			

Annual Trip and Harvest Estimates

From the results of our tournament inventory (number of tournaments and number of anglers per tournament) and the mail survey (number of tournaments per angler), we estimated 7,915 U.S. tournament billfish anglers in the western Atlantic Ocean in 1989. This group makes a total of 102,895 ± 6,512 (90% confidence interval) billfish fishing trips per year (both tournament and nontournament), or 266,498 days per year. On 40% of these trips a billfish was caught. These anglers caught 42,301 billfish, released 89% of their catch, and landed 5,541 ± 715 (90% confidence interval) billfish. The total catch was composed of 38% sailfish, 33% blue marlin, 29% white marlin, and <1% spearfish. Of the billfish landed, 59% were blue marlin, 24% were white marlin, 15% were sailfish and the remainder spearfish. Tournaments accounted for only 25% of the annual billfish landings for this group of anglers. Whereas we were unable to make estimates for the population of nontournament billfish anglers, we would expect catch rates to be higher for tournament billfish anglers.

Annual Expenditure Estimates in the Study Area

Billfish tournament anglers spent an estimated $179,425,000 in pursuit of billfish (tournament and nontournament trips). This equals $4,242 per billfish caught or $32,381 per billfish landed. Included in the total were billfish tournament expenses of $58,964,000, of which $14,690,000 were tournament fees. This amounts to $5,576 for every tournament-caught billfish and $42,565 for every tournament-landed billfish.

Annual Consumer's Surplus in the Study Area

At current billfish population levels, the annual net economic benefits for this group of anglers was $2,073,730

for the opportunity to fish for billfish. If the numbers of billfish were to increase by 25%, annual net economic benefits would be $3,545,920. Thus, by subtraction, the net benefits gained from a 25% increase in the billfish population would be $1,472,190 for this group of anglers.

Discussion

Billfish tournament anglers are a unique segment of saltwater anglers. Their fishing frequency of 44 days per year far exceeds the 11 days reported by saltwater anglers nationwide (USFWS, 1988). Greater fishing frequency and years of previous experience probably account for why almost 40% of billfish anglers rated themselves "more skilled" than other anglers, contrasted with 13% of the statewide population of Texas saltwater anglers (Ditton et al., 1990). The cost of a billfish fishing trip ($1,601) is about 7 times higher than the cost of a king mackerel trip in the Gulf of Mexico ($226) (Stoll et al., 1989). Similarly, per-day billfishing costs ($618) are about 13 times higher than general daily saltwater fishing expenses in 1985 ($47) (USFWS, 1988).

Regulations that would diminish billfish anglers' ability to catch (not land) a billfish would likely meet strong opposition. Therefore, if further regulation of the recreational fishery becomes necessary, decisionmakers might consider a management regime that would achieve the desired objective but not deter or inhibit anglers from catching billfish (e.g., seasonal or area closures). Since most billfish are released, stricter size requirements, daily limits, or annual bag limits would have little or no impact on anglers who release billfish. Further regulations may not be necessary if fishery conservation groups generate greater support for catch and release programs among Caribbean anglers. Support for catch and release has long been established in the fishery and is expanding (Prince et al., 1990).

Results support the decision to reserve billfish for the recreational fishery. Billfish anglers have a low success rate and an even lower retention rate; their effect on billfish populations is slight, while the economic value of a billfish trip is great. The annual consumer's surplus of a billfish angler ($262) is almost 10 times higher than king mackerel anglers in the Gulf of Mexico in 1987 ($27) (Stoll et al., 1989). Further, decommercialization of the billfish fishery should increase billfish populations and increase social and economic benefits to the nation ($448 per angler annually with a 25% increase in billfish). Also, current regulations do not deny commercial fishermen their directed fishery (tuna or swordfish). If domestic and foreign longliners are allowed to deplete billfish on a bycatch basis to where anglers no longer feel they have an opportunity to catch them, current economic benefits could be lost. Also, there would be impacts of lost revenues on providers and local communities.

Current U.S. management efforts are a step in the right direction toward billfish conservation. Whereas billfish available to U.S. recreational anglers can be affected by overfishing by foreign fleets (external to our EEZ), this can only be resolved through international efforts, i.e., the International Convention for the Conservation of Atlantic Tunas (ICCAT).

Acknowledgments

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Effects of the Santa Barbara, Calif., Oil Spill on the Apparent Abundance of Pelagic Fishery Resources

JAMES L. SQUIRE, Jr.

Introduction

Many studies have been made of the effects of oil on marine invertebrates, plants (marine algae and phytoplankton), and vertebrates such as seabirds and marine mammals. An excellent review of these findings, which includes some references to fish and pathological effects of aromatic hydrocarbons, has been published by the Royal Society, London (Clark, 1982). That review dealt with the environmental effects of such major oil spills or releases such as those by the tankers *Torry Canyon* (119,000 t) on the south coast of England, *Metula* (50-56,000 t) in the Straits of Magellan, *Argo Merchant* (26,000 t) off Cape Cod, and the super tanker *Amoco Cadiz* (223,000 t) on the coast of northern Brittany. Those spills were studied to determine their effect on living resources. In contrast there are few references on the impact of oil spills on pelagic fishery resources.

The release of approximately 240,000 barrels (bbl) (34,800 t) of Alaskan crude oil by the tanker *Exxon Valdez* in Prince William Sound, Alaska, in March 1989, has created increased public interest on the effects of petroleum spills on biological resources.

The largest crude oil spill off California resulted from the blowout of the subsurface oil well casing at the Union Oil Company Platform A in the Santa Barbara Channel (Fig. 1) about 6.5 miles southeast of the City of Santa Barbara, California. This spill started on 28 January 1969 and continued at rates of up to an estimated 5,000 bbl per day into April 1969 with some discharge of crude oil continuing after this time. A crude oil line break in December 1969 resulted in a spill of additional oil into the Santa Barbara Channel. Extensive areas of crude oil in the Santa Barbara Channel were evident into 1970. The total amount of crude oil spilled at Platform A is unknown and can only be estimated; this is in contrast to the reasonably accurate measurements from tanker spills. A U.S. Department of the Interior publication (Anonymous, 1979) reported estimates of 33,000 bbl (4,782 t) spilled at Platform A; another reference in the same publication estimated 77,000 bbl (11,159 t).

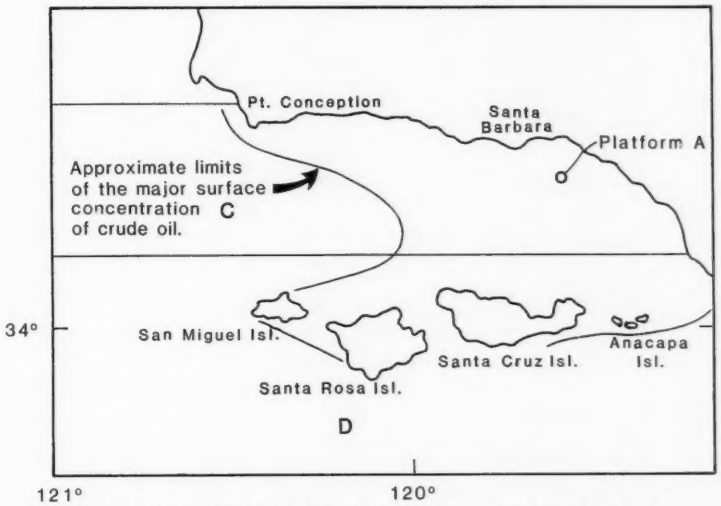

Figure 1.—Approximate limits of major surface concentrations of crude oil.

Crude oil on surface waters in the Santa Barbara Channel is not uncommon. The Santa Barbara Channel and submerged areas about the Islands are known to have several hundred natural subsurface oil seeps. These seeps are variable in their discharge rates and are estimated to have a total spill level of 40-670 bbl per day (Anonymous, 1979). A spill level of 200-400 bbl per day would be a reasonable estimate. At a rate of 300 bbl per day, the natural spill in this area would be over 15,800 t of crude per year. In addition to seeps in this area, other oil seeps are present to the southeast off the southern California coast, some existing in the San Pedro Channel.

The crude oil from the Platform A spill spread throughout the Santa Barbara Channel with major concentrations in the eastern half of the Channel. The surface concentration of crude oil extended offshore to the southeast to

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Anacapa and Santa Cruz Islands in particular (Fig. 1). The distribution of oil on the surface was highly variable after the initial release. Concentrations were continually shifting relative to changes in surface currents.

The area covered by crude oil included one of the more important commercial fishing areas for pelagic fish resources, including the northern anchovy, *Engraulis mordax*; Pacific sardine, *Sardinops sagax*; Pacific mackerel, *Scomber japonicus*; Pacific bonito, *Sarda chiliensis*; and jack mackerel, *Trachurus symmetricus*. Pacific sardine and Pacific mackerel, two important commercial species, were at very low levels of abundance at the time of the oil spill (Squire, 1983).

Surface concentrations of crude oil which spread over the Santa Barbara Channel area affected seine fishing. The oil film and its resulting surface sheen impaired the ability of the boat crews to sight schooling fish. Also, any fish caught would probably have been tainted with hydrocarbons and not desirable for public consumption (McIntyre, 1982). After natural dispersion of the initial oil spill by currents, purse seine operations could be conducted in clear areas. Aerial fish spotters were able to see fish schools swimming below the surface oil slick, and when the fish school would move out from under the oil slick into an area clear of crude oil, purse seining operations could be conducted.

In 1962, several years before the Platform A spill, the National Marine Fisheries Service (then called the Bureau of Commercial Fisheries) started an aerial monitoring program for pelagic fishery resources common to the central and southern California coast (Squire, 1972, 1983). This program utilizes the services of commercial aerial fish spotter pilots who search for the commercial purse seine fleet operating off southern California. The program was operating and collecting data on the relative apparent abundance (Marr, 1951) of pelagic fishery resources in the Santa Barbara Channel and offshore islands area at the time of the Platform A blowout.

This paper reviews the relative apparent abundance of three commercially important pelagic species common to the Santa Barbara Channel and Island areas prior to, during, and for a 3-year period after the oil spill.

Methods

Monitoring Program Procedures

On a flight log sheet, aerial fish spotter pilots under contract to the NMFS Southwest Fisheries Science Center (SWFSC), record information on their flight track, locations of various species observed, and an estimate of tonnage observed. The flight logs are edited and the data are coded into the SWFSC data base. Flight log data were converted to an index of apparent abundance by dividing the tonnage observed by the number of block areas (lat. 10" × long. 10"—about an 8 × 10 n.mi. area at the latitude of southern California) entered into during each flight (a measure of observation effort) to give a measure of tons per block area flight (T/BAF). Flight log data represent a sample estimate of the abundance of pelagic species schooling in near surface layers of the ocean surveyed. Flight tracks flown by the spotter pilots are nonrandom, being determined by previous experience regarding the most likely locations for sighting schools of various species relative to the season of the year, real-time information from other aerial spotters or fishing boats, and other recent experiences. In zones where concentrations of fish are historically found, the same block areas tend to be searched every year. For details of the aerial program see Squire (1972, 1983).

Due to the behavior of schooling fish, some species are observed more frequently and in greater amounts during the day, others at night. Sampling differences during day or night could affect the apparent abundance. The ratio of day to night flight operations, 35% night and 65% day, was similar during the oil spill period as for the total program (1963-88). For night observations, near total darkness is required to observe the bioluminescent glow of plankton organisms being agitated by the fish school. Analysis of time of sighting (day or night) indicates the northern anchovy and jack mackerel are usually observed in greater numbers and more frequently at night, and Pacific bonito in greater frequency and abundance in the day. However, there may be considerable variation in the day/night ratio of sighting during any one year. During the period 1966-72 (before, during, and after the oil spill), 72% of the flight effort was during the day, and 28% was during the night in the Santa Barbara Channel and Islands area (Zones C and D, Fig. 1). In 1969, the year of the oil spill, only a small difference in day/night ratios was noted, with 75% of effort (# BAF searched) during the day and 25% at night. A total of 269 individual survey flights were conducted in 1968, 399 in 1969, and 224 in 1970.

Indices of Abundance

An index of abundance was calculated for each species for groups of block areas or "zones." Zone "C" includes the Santa Barbara Channel and Zone "D" includes the Santa Barbara Channel Islands (Fig. 1). Platform A is located in Zone C, and this zone was the area most affected by the oil spill.

A simple, direct formula is used for the calculation of an index of apparent abundance for each species in the various zones such as Zones C and D, and procedures on calculation are given by Squire (1972, 1983). The index of apparent abundance is expressed in terms of tons per block area flight (T/BAF). Figure 2 gives the amount of search effort (# BAF) for 3 years before and after the oil spill period of 1966-72.

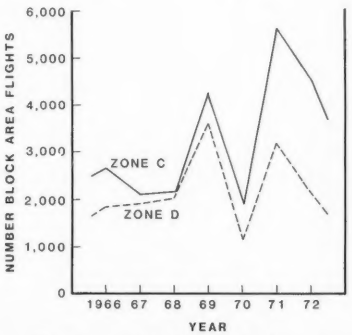

Figure 2.—Number of block area flights conducted in Zones C and D by year, 1966-72.

Results

Distribution of Species Sightings

The geographical distribution of the sightings in the Santa Barbara Channel and about the Channel Islands of the northern anchovy, Pacific bonito, and jack mackerel for the periods 1966-69, and 1970-73 are given in Figures 3-5. Each dot represents the sighting location by a spotter pilot indicating the location of one or more schools (school group) of fish sighted.

Changes in Abundance

Sightings records (1963-88) for the Santa Barbara Channel and Islands areas indicate that the summer-to-winter period has a greater abundance of northern anchovy, jack mackerel, and Pacific bonito. In some years the fishing season for Pacific bonito extends into February or March. The abundance levels of each species of interest are reviewed in the following section by monthly periods before and after the January 1969 oil spill. Flights conducted in the Santa Barbara Channel and Island areas were examined for a 36-month period, 1 year before the oil spill, the year of the oil spill, and 1 year after (January 1968 to December 1970). A total of 269 flights were recorded in 1968, 399 in 1969, and 224 in 1970. Information is given regarding total tonnage observed by month for Pacific bonito, northern anchovy, and jack mackerel (Table 1).

The trend of the abundance index (night index for anchovy and jack mackerel and day index for bonito) for Zones C and D, all sightings, calculated in T/BAF for the three species, 1966-72 is given in Figures 6-8.

Discussion

In contrast to extensive studies on birds and invertebrates, there have been some studies on the effects of the Santa Barbara oil spill on fishes. In February 1969, the NOAA research vessel *David Starr Jordan* sampled the area with plankton nets and found no oil adhering to the fish eggs or any abnormalities in them (Anonymous, 1979). Samples taken directly under the oil indicated fish larvae were in usual numbers and kinds representative of that area at that time of the year. NOAA concluded that the oil spill at that time had no major discernible effect on the planktonic biota (Anonymous, 1970).

The California Department of Fish and Game sampled pelagic species in the Santa Barbara Channel about 15 days after the initial oil spill and found no evidence of starvation in the northern anchovy that might have resulted from impairment of the planktonic food chain (Anonymous, 1979). No changes from the expected composition of ichthyoplankton were observed. Preliminary information on the results (number of flights and estimates of tons observed) of aerial spotting flights in the Santa Barbara Channel area were made available and were used in development of the conclusion by Straughan (1971) that fish were still present in the Santa Barbara Channel after February 1969. However, no supportive analysis was given relative to changes in abundance before, during,

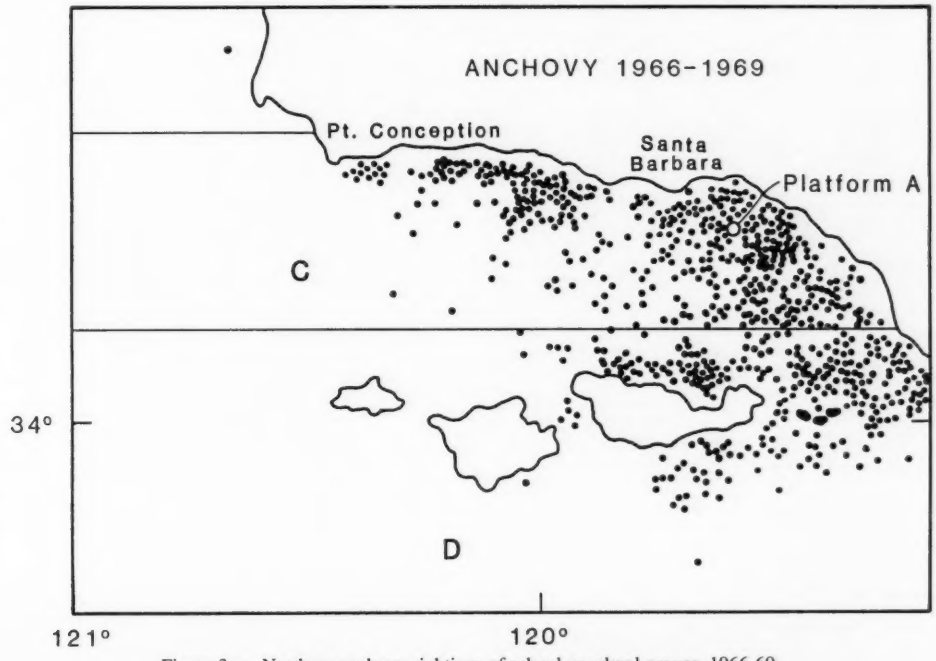

Figure 3a.—Northern anchovy sightings of school or school groups, 1966-69.

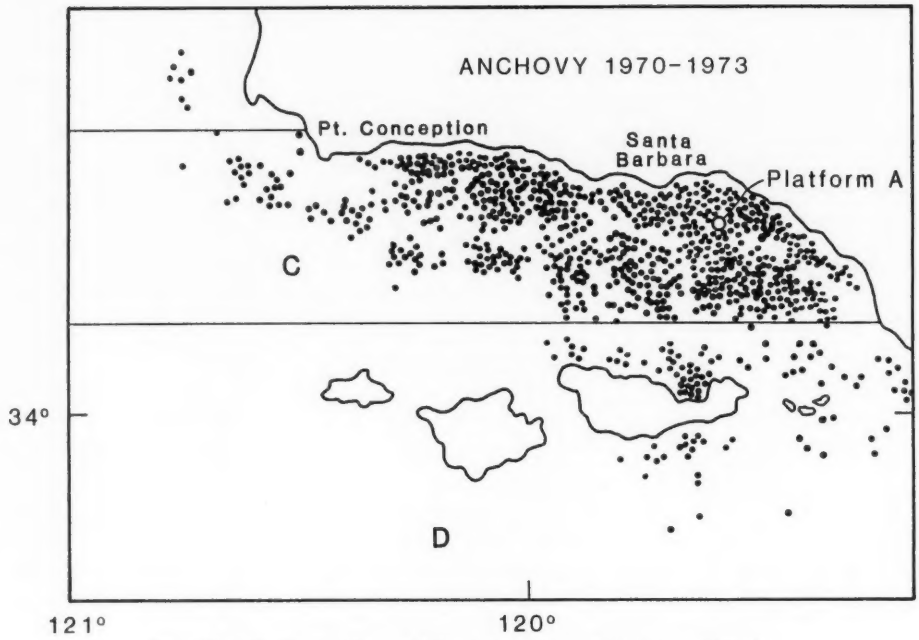

Figure 3b.—Northern anchovy sightings of school or school groups, 1970-73.

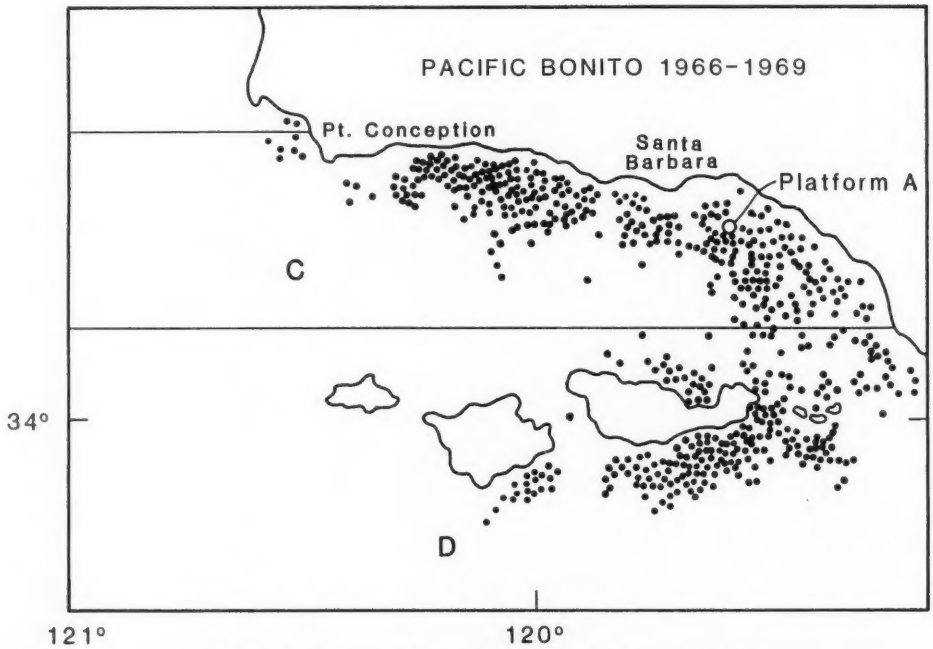

Figure 4a.—Pacific bonito sightings of school or school groups, 1966-69.

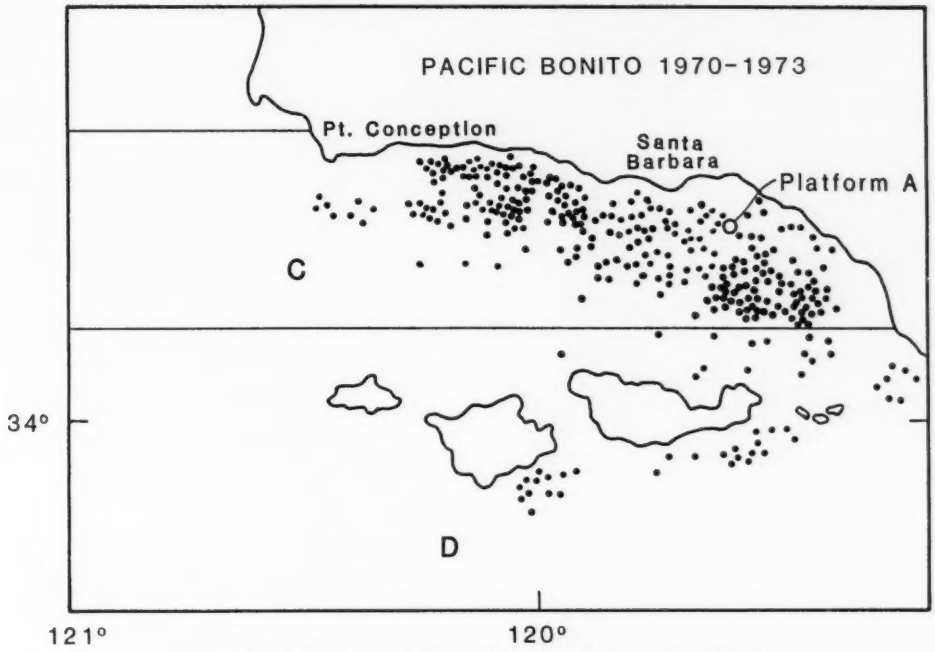

Figure 4b.—Pacific bonito sightings of school or school groups, 1970-73.

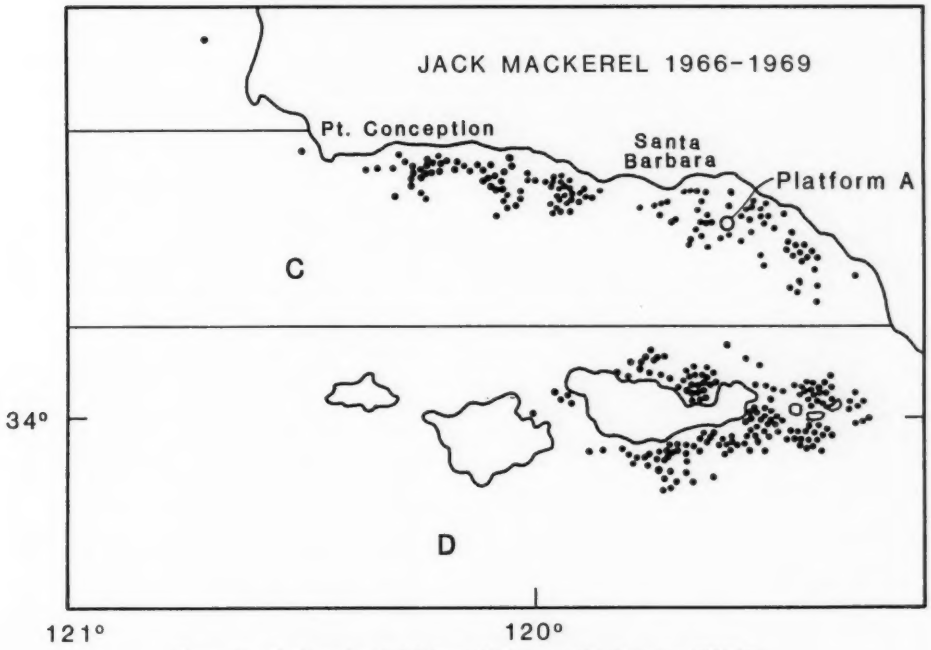

Figure 5a.—Jack mackerel sightings of school or school groups, 1966-69.

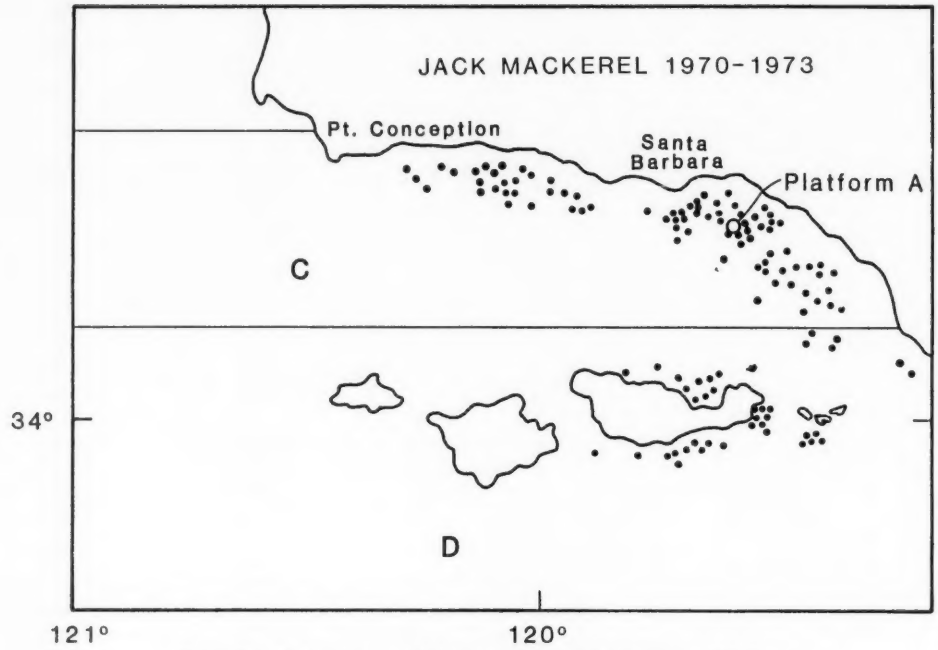

Figure 5b.—Jack mackerel sightings of school or school groups, 1970-73.

or after the oil spill. Straughan (1971) also concluded that the reduction in fish catch was probably due to the problems of fishing in oily waters rather than the lack of fish.

The Platform A blowout spilled a large quantity of crude oil into the waters of the Santa Barbara Channel and Islands. A small amount of crude oil was noted along the coast as far southeast as Newport Beach, Calif. This crude oil spill is the largest recorded in California waters. The major difference between the Platform A blowout and tanker disasters is that the crude oil release from the blowout extended over a period of time in contrast to the short-term release of oil in most tanker accidents.

In addition to the accidental release in 1969, the marine environment of the Santa Barbara Channel and other southern California areas have been subjected historically to a continuing seepage of crude oil into the water column. What effect this has had in the pelagic fishery resources and other biological resources common to the area is unknown. The pelagic species with which this paper is concerned are commonly found in the Channel, primarily in the eastern half and about the Islands as the sighting graphics (Fig. 3a-5b) would indicate. In an analysis of the aerial monitoring program (1963-89) (Squire[1]), "core areas" of distribution and abundance were defined for each species. Zones having considerable crude oil release are included in the core areas for Pacific sardine, northern anchovy, Pacific mackerel, Pacific bonito, and jack mackerel. This analysis would indicate that the natural oil seepage is not having substantial negative effect on the distribution of these pelagic resources.

The results of aerial spotting records for Zones C and D (Fig. 6-8) and monthly summaries of tonnages from flight observations in the Santa Barbara Channel and Islands area, (Table 1) are reviewed for Pacific bonito, northern anchovy, and jack mackerel.

Northern Anchovy

After the oil spill at the end of January 1969, the northern anchovy was absent in February but was observed during the late spring early-summer months at higher abundance levels than observed in either 1968 or 1970; however, the abundance level showed a decline in 1970 (Table 1).

The trend of abundance index (day index, T/BAF) for Zones C and D are given in Figure 6. Zones C and D are zones where high abundance index levels of anchovy are normally observed, with Zone C an important area for the northern anchovy. Zone C peaked in 1967 with a low in 1968, but increased during the oil spill year, 1969. Zone D peaked in 1968 with a low index level in 1969. Both Zones C and D were at lower levels in 1970, increasing in 1971 (Fig. 6).

[1]Squire, L. 1992. Apparent abundance indices for six pelagic species—1962-1990, as determined by an aerial monitoring program. U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Southwest Fish. Sci. Cent., Admin. Rep. LJ-92-12, 15 p.

Table 1.—Summary of individual aerial fish spotting flights (1968-70) for the Santa Barbara Channel and Islands (for Zones C and D combined) and the estimated tonnage sighted, by month, from records of five spotters.

Year	Distribution of individual flights	Estimated tonnage[1] sighted		
		Bonito	Anchovy	Jack mackerel
1968				
Jan.	31	4,042	1,450	22
Feb.	29	1,892	4,100	140 C
Mar.	23	203	840	87
April	0			
May	9	0	70	651
June	20	0	2,670	198
July	21	245	4,506	974
Aug.	32	1,650	595	539
Sept.	53	3,784	3,978	1,085
Oct.	17	166	55,000	210
Nov.	18	445	149,800	0
Dec.	16	1,400	46,900	10
	269			
1969				
Jan.[2]	13	1,799	7,000	415
Feb.	14	0	0	30
Mar.	28	0	39	1,610
April	19	0	435	602
May	20	0	20,310	142
June	34	5	76,236	580
July	52	399	101,036	2,071
Aug.	58	2,531	649	106
Sept.	28	348	53,130	260
Oct.	48	4,350	26,885	40
Nov.	45	525	80	683
Dec.	40	999	51,560	287
	399			
1970				
Jan.	23	310	4,030	885
Feb.	23	0	207	1,104
Mar.	37	0	3,614	865
April	24	0	4,100	315
May	19	0	8,406	84
June	18	2	11,750	305
July	12	10	8,452	4
Aug.	17	1,221	2,113	17
Sept.	17	2,627	13,130	14
Oct.	13	1,103	4,799	43
Nov.	12	484	945	6
Dec.	9	851	522	0
	224			

[1]Short tons.
[2]Oil spill started January 28, 1969, continued unchecked to April 1969, and continued a minor flow until late in the year.

Jack Mackerel

The jack mackerel resource has a distribution of older adults generally offshore from which the younger year classes recruit into the southern California fishery. The jack mackerel tonnages decreased after the spill, but, overall, increased slightly in 1969, then decreased in 1970 (Table 1). For Zones C and D the index of apparent abundance (night index, T/BAF) was at a low level in 1968 prior to the oil spill and remained at a low level after 1969 through 1972 until showing an increase in 1975 (Fig. 7) (Squire, 1983).

Pacific Bonito

The Pacific bonito fishing season in the Santa Barbara area usually extends from the summer months into the following winter months of February or March. The 1967-68 fishing season ended in February/March 1968. Starting in August 1968, prior to the oil spill, these high abundance levels extended through January 1969, with very high levels just prior to the oil spill. After the oil spill, Pacific bonito were not observed, but they were again observed in increased abundance in July/August 1969, about the same months as initially observed in 1968. Abundance levels remained up until January 1970. Again in 1970, as in previous years, Pacific bonito were absent from February to May with a substantial increase in abundance noted in August (Table 1).

The apparent abundance index trend (day index, T/BAF) of Pacific bonito in Zones C and D (Fig. 8) follows a steady overall decline (1966-70) in its apparent abundance index prior to the oil spill. The declining trend then shifted to an increase in apparent abundance starting in 1971 and continued into 1972.

Conclusions

A review of the trends of abundance index as calculated for Zones C and D (Figs. 6-8) and of tonnages sighted during observational flights prior to, during, and after the Platform A blowout (Table 1), indicates that the oil spill had some immediate short-term (monthly) negative effects on the apparent abundance of Pacific bonito and jack mackerel. The northern anchovy abundance index in the important Zones C and D were relatively stable from 1968 through 1971, particularly for Zone C, one of the more important zones for evaluating changes during the oil spill period.

The variability in the occurrence and concentrations of pelagic species is difficult to measure and is confounded by variables in the abundance and behavior, the fishes' relation to their environment and its changes, interaction with predators, and wide fluctuations in recruitment. The oil spill occurred

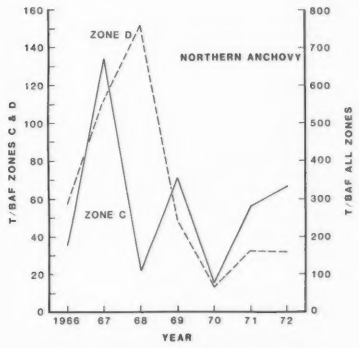

Figure 6.—Trend of abundance in T/BAF for northern anchovy (night index) in Zones C and D, 1966-72.

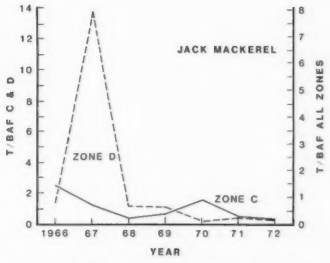

Figure 7.—Trends of abundance in T/BAF for jack mackerel (night index) in Zones C and D, 1966-72.

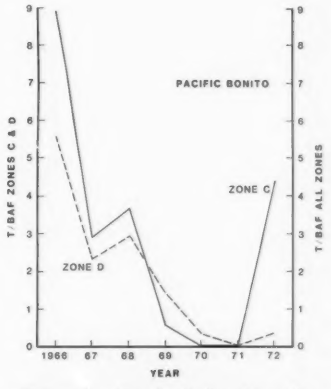

Figure 8.—Trend of abundance in T/BAF for Pacific bonito (day index) in Zones C and D, 1966-72.

in an environmentally unique area where, historically, high levels of crude oil, emanating from underwater oil seepage, are present. Fluctuations in sea surface temperature has a substantial effect on fish distribution. An El Niño event occurred in 1972 and may have been a contributor to increased abundance of Pacific bonito and movement of the northern anchovy in more northern waters including the study area. However, abundance index values during the oil spill year of 1969 do not indicate any unusually reduced fish abundance levels resulting from the oil spill.

Observations during the oil spill period indicated that schools of anchovy, bonito, and jack mackerel were in the normal geographical areas of distribution within the Santa Barbara Channel and Islands, and that their behavior, below the oil slick was normal relative to depth, movement, and school shape[2]. Data would indicate that pelagic fish resources, with their capability of moving widely in their environment, do not suffer short-term debility from localized oil spills, such as the type that occurred during January 1969 in the Santa Barbara Channel.

Acknowledgments

Assistance in the development of this paper by David Au is appreciated.

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Remote Camera and Trapping Survey of the Deep-water Shrimps *Heterocarpus laevigatus* and *H. ensifer* and the Geryonid Crab *Chaceon granulatus* in Palau

W. B. SAUNDERS and LEE C. HASTIE

Introduction

Deep-water bottom-dwelling communities of the Indo-Pacific are not well known, owing to their relative inaccessibility. Most available information has been derived from trapping-based surveys which, for the most part, have been pilot efforts directed at evaluating economic potential of deep-water shrimps (King, 1980, 1982, 1984; Struhsaker and Aasted, 1974; Gooding, 1984). These surveys have generated information on species identifications, geographic dispersal, and depth ranges, as well as population characteristics such as size-distribution, sex ratios, etc. More sophisticated analyses of larger trapping data bases have been used to describe reproductive biology, growth, and mortality (Dailey and Ralston, 1986), and to calculate potential exploitable biomass and sustainable yields under intensive fishing pressure (Polovina et al., 1985; Ralston, 1986; Moffitt and Polovina, 1987; Tagami and Ralston, 1988). Only recently has it been logistically possible to attempt to study the deepwater habitat directly, and several recent efforts using a submersible show much promise (Ralston et al., 1986; Moffitt and Parrish[1].

In Palau, Western Caroline Islands, a series of remote camera investigations of the chambered nautilus, which inhabitats the deep forereef slope at depths of 100-500 m, revealed the presence of large numbers of the deep-water caridean shrimps *Heterocarpus ensifer* and *H. laevigatus* (as many as 150 shrimps in a single photographic frame), plus the marketable geryonid crab *Chaceon granulatus*[2] at depths below 400 m (Saunders, 1984). These findings suggested that it would be worthwhile to utilize a remote camera in conjunction with a conventional trapping survey to study shrimp behavior and trap effectiveness as part of an effort to evaluate the potential for a small-scale deep-water shrimp fishery in Palau (Saunders et al., 1989[3]).

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ABSTRACT—Time-lapse remote photosequences at 73-700 m depth off Palau, Western Caroline Islands, show that the caridean shrimp Heterocarpus laevigatus *tends to be a solitary animal, occurring below ~350 m, that gradually accumulates around bait sites over a prolonged period. A smaller species,* H. ensifer, *tends to move erratically in swarms, appearing in large numbers in the upper part of its range (<250 m) during the evening crepuscular period and disappearing at dawn. Trapping and photosequence data indicate the depth range of* H. ensifer *(during daylight) is ~250-550 m, while* H. laevigatus *ranges from 350 m to at least 800 m, along with the geryonid crab* Chaceon granulatus. *Combined trapping for* Heterocarpus laevigatus *and* Chaceon granulatus, *using a three-chamber box-trap and extended soak times (48-72 h), may be an appropriate technique for small-scale deep-water fisheries along forereef slopes of Indo-Pacific archipelagoes.*

Procedures

Trapping

A total of 103 traps was set between 170-900 m depth at five sites around Palau (Fig. 1) during May-October 1987 and 1988. The following trap designs were used during the survey: 1) A small collapsible trap (60 x 40 x 20 cm); 2) a large pyramidal trap (2 m square at the base x 1.5 m high); 3) a traditional fish trap design (1.5 x 1 x 1 m); 4) a covered box trap (1.5 x 0.5 x 0.5 m); 5) a small box-shaped trap (1 x 1 x 1 m) attached to a camera frame for photographic purposes; 6) a large box trap (2 x 1 x 1 m) with 25 cm diameter funnels at each end (this design was used for quantitative data and is referred to as the "standard trap"); and 7) a modified standard "combined" trap containing a central chamber with two additional (10 cm diameter) funnels (Fig. 2). About 1 kg of bait (tuna, shark, clams or deep-water eels), was placed in a fine wire-mesh bait bag or wrapped in chicken wire and suspended in the center of the trap. Polypropylene rope (4-8 mm diameter) as well as standard longline rope (4 mm diameter) was used in conjunction with surface buoys and marker flags. Single traps were deployed, with double anchors (scrap iron or cement) and sand anchors to reduce dragging.

[1]R. B. Moffitt and F. A. Parrish. Comparison of submersible observations of shrimp densities with trap catches for *Heterocarpus laevigatus* in Hawaii. Manuscr. in prep.

[2]The family Geryonidae has recently been revised by Manning and Holthuis (1989) to include two new genera, one of which, *Chaceon*, includes the Palauan species *C. granulatus*.

[3]W. B. Saunders, L. C. Hastie, and T. Paulis. 1989. Deep-water shrimp survey and feasibility study, Republic of Palau, Western Caroline Islands. Pac. Fish. Develop. Found., Honolulu, Final Rep., Proj. 63A, 120 p.

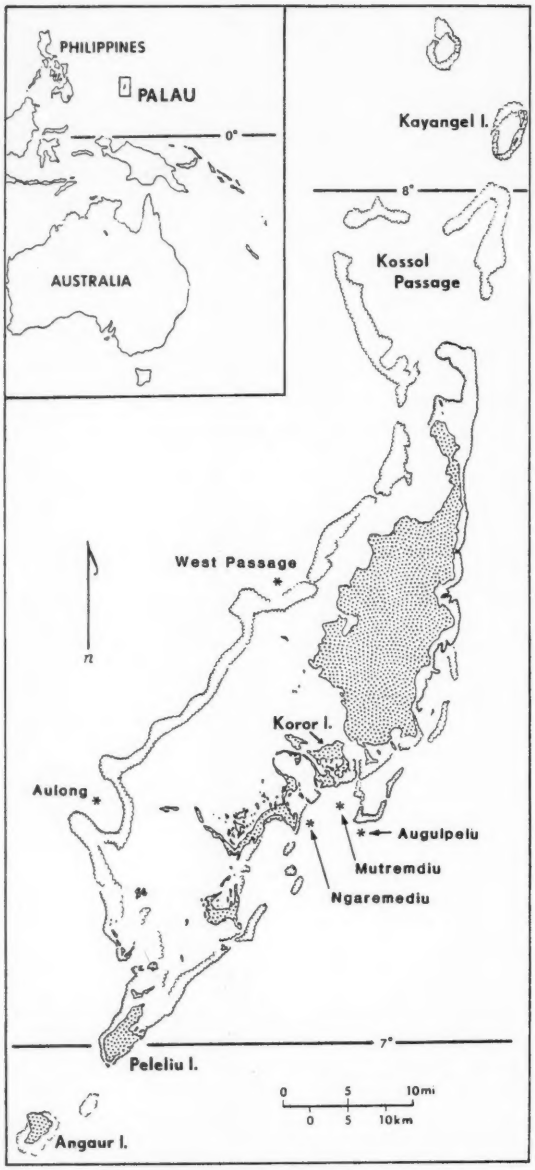


Figure 1.—The deep-water trapping and remote camera sites around Palau, Western Caroline Islands.

Water temperature profiles were obtained with a HUGRUN[4] Seamon Immersible Temperature Recorder, programmed to record temperature at specific time intervals while lowered slowly to the bottom.

The survey vessel was a diesel 10 m Yanmar equipped with a gasoline pot hauler. The catches were sorted in the laboratory according to species and whether ovigerous and measured for body weight and carapace length. These also were sexed, and tail weight, body weight, and egg color were noted.

Remote Camera Photosequences

Photosequence records show several aspects of shrimp behavior and distribution that are relevant to fisheries considerations. This study focused on the two caridean species *Heterocarpus laevigatus* and *H. ensifer* which, because of their greater abundance or size, are the two forms that have commercial potential in Palau (and, in general, at other Pacific localities; King, 1986). The use of a remote, deep-water camera to obtain time-lapse photosequences at baited bottom sites followed approaches developed to study *Nautilus* in Palau (Saunders, 1984, 1985).

The camera unit consists of a standard, motor-driven 35 mm camera coupled to an integrated electronic timing circuit that permits preselection of exposure interval. The light source (a xenon strobe) and timing circuit are powered by 12 v DC (2.4 amp) nicad batteries. The camera and strobe fit into tubular aluminum housings with Plexiglas[4] ports that will withstand hydrostatic pressures equivalent to 1,000 m depth. The camera is attached to a welded rebar frame, providing an obliquely illuminated field of view about 2 m by 1.5 m, focused on a baited trap about 1.5 m away (Fig. 3). The camera is lowered to the bottom, attached to a surface buoy, and tended for the duration of the photosequence. Exposure intervals of 15 and 30 min, respectively, provide 9 and 18 h photoseqences from a 36-exposure roll of film (Kodachrome 64 or Ektachrome 100). A total of 27 photosequences was obtained; of these, numbers 1-22 were taken off Mutremdiu, in conjunction with *Nautilus* studies (see Saunders, 1984), and numbers 23-27 were taken in West Passage in 1988.

[4]Mention of trade names, trademarks, or commercial firms does not imply endorsement by the National Marine Fisheries Service, NOAA.

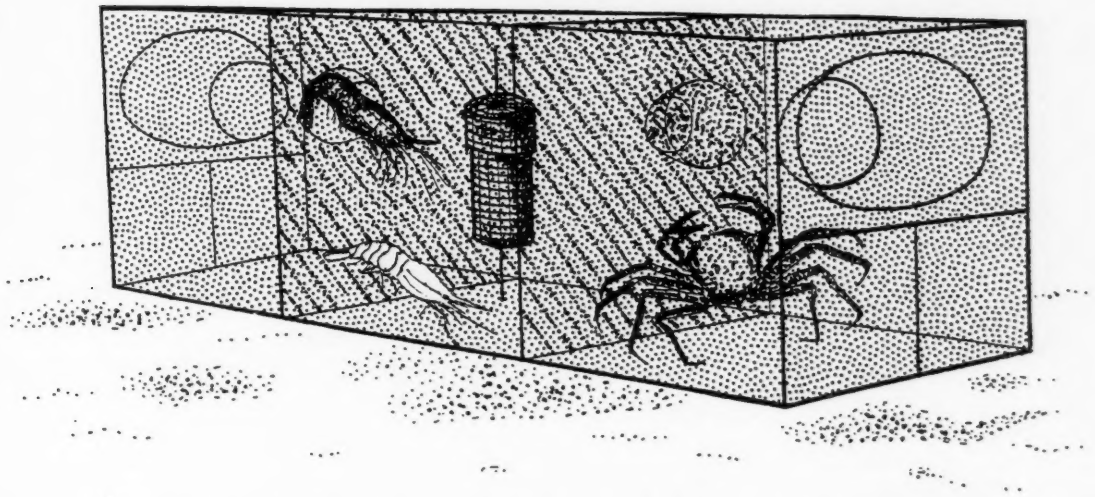


Figure 2.—Three-chambered box-trap for combined shrimp/crab trapping. Crabs (*Chaceon granulatus*) accumulate in the two outer chambers; shrimps are able to enter the central bait chamber, but their escape is impeded by the smaller funnels.

Analysis of the photosequences involved study of each transparency using a stereomicroscope with transmitted light. The identity and number of each organism and any activity within the field of view were tabulated against actual time or elapsed bottom time.

Results

Trapping

Traps were set 103 times at 170-900 m depth, at Mutremdiu Bay (38 sets), Augulpelu Reef (7 sets), Ngaremediu Reef (19 sets), Aulong Bay (7 sets), and Toagel Mlungui (West Passage; 32 sets; Fig. 1). A total of 98 retrieved traps (five were lost) yielded 1,550 shrimps (15 species, 55.08 kg) and 232 geryonid crabs (*Chaceon granulatus*, 268 kg; Table 1).

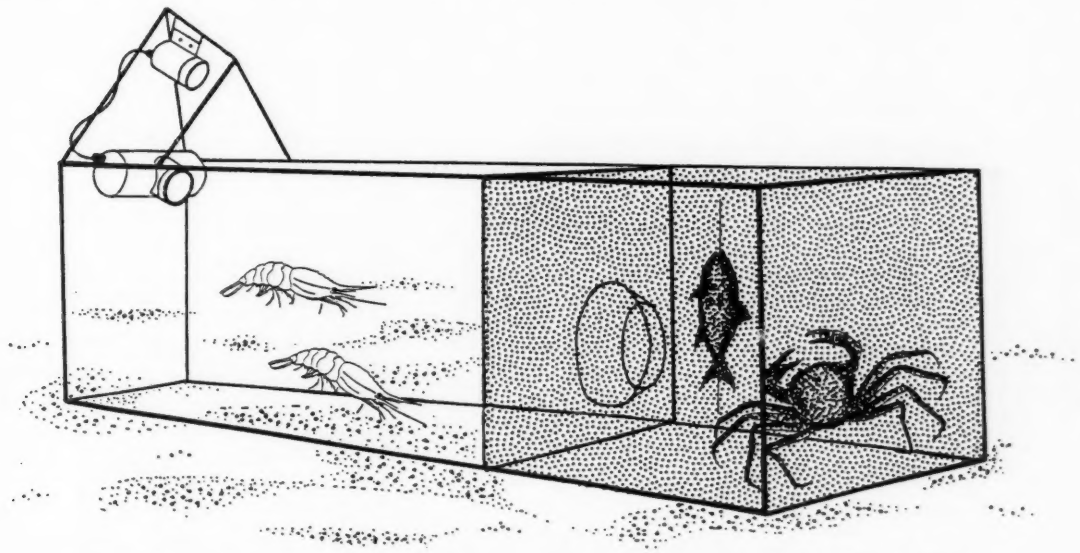


Figure 3.—Remote 35-mm still camera, strobe, frame, and trap used to obtain photosequences. The unit is attached to a rope harness, lowered to the bottom, and tethered to a surface buoy for the duration of the photosequence (trap width 1 m).

The best results were produced from the combined standard trap (Fig. 2). Crabs were caught in the outer chambers of this trap, while shrimps were concentrated in the central bait chamber, from which the smaller funnels impeded egress. Using soak times of 48-72 h, this design produced a per-trap average of 1.45 kg of shrimp and 5.09 kg (~6 individuals) of the large crab *Chaceon*. By contrast, the other trap designs, set for shorter soak times (~24 h) averaged 0.84 kg of shrimps and 2.54 kg of crabs (Table 2).

The shrimp catch was dominated by *Heterocarpus laevigatus* which comprised 92% (51 kg) of the total yield by weight. The smaller species, *H. ensifer*, dominated the shallower (170-400 m) catches, but these catches were generally poor; thus, this species composed only 3% of the total yield by weight (1.52 kg). Shrimp yields >1 kg per trap-night were obtained at each site surveyed, generally between 500 and 800 m, with corresponding water temperatures 6-8°C.

A complete data set was obtained for 693 specimens of *H. laevigatus*, 163 specimens of *H. ensifer*, 150 specimens belonging to four other shrimp taxa, and for 184 specimens of *Chaceon granulatus*. By-catches included 83 eels (10 *Conger* sp., remainder *Synaphobranchus affinis*), 52 *Nautilus belauensis* (<500 m), 21 unidentified crabs (belonging to three noncommercial species), 7 sharks (including *Squalus* sp.), 3 red snappers (*Etelis carbunculus*) and 16 other unidentified teleosts; one *Octopus* sp., and one ophiuroid.

Individual wet weights for *Heterocarpus laevigatus* varied from 2-106 g ($\bar{X}$ = 41 g; Table 1, Fig. 4a). In 675 specimens in which sex could be determined, females slightly outnumbered males (363:312), with a male:female ratio of 1:1.16 (Fig. 5a), and 245 (67.5%) females were ovigerous. Carapace length ranged from 17.2 to 63 mm ($\bar{X}$ = 44.1 mm), and females averaged slightly larger than males ($\bar{X}$ = 47.3 vs. 41.6 mm). Female *H. laevigatus* appear to become ovigerous at ~40 mm carapace length, and at 50 mm most of the females collected were ovigerous (Fig. 5b).

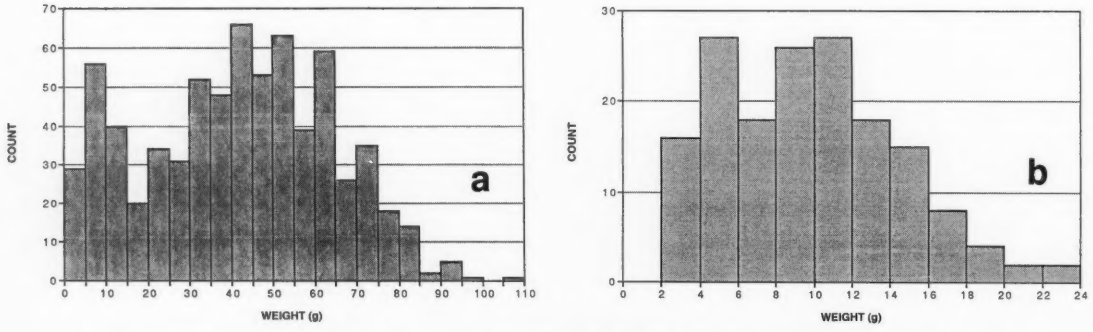
The smaller species, *H. ensifer*, ranged from 2 to 22 g ($\bar{X}$ = 8.8 g; Table 1, Fig. 4b). Females outnumbered males 91:51 (1:1.78), and 47 (51.6%) of the 91 females were ovigerous. Cara-

Table 1.—Summary data on depth-range, number of specimens, carapace size, and wet weight for shrimps H. (*Heterocarpus*), P. (*Plesionika*), Pl. (*Plesiopenaeus*) and for *Chaceon*. Other species obtained in small numbers include *Plesionika martia* (308 m), *P. longirostris* (448 m), *P. rosticresentis* (380-704 m), and *Plesionika* sp. (520-850 m).

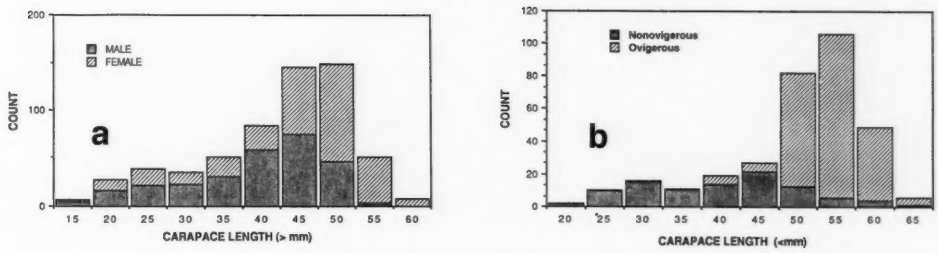
Species	Depth range (m)	No. of specimens	Carapace (mm) Mean	Carapace (mm) (Range)	Weight (g) Mean	Weight (g) (Range)
H. laevigatus	320-850	693	44.1	(17.2-63.0)	41	(2-106)
H. ensifer	170-480	163	25.3	(6.5-35.9)	8.8	(2-22)
H. gibbosus	208-380	15	38.9	(33.6-44.9)	34	(24-42)
H. dorsalis	560-850	24	25.6	(16.0-43.6)	10	(2-32)
P. ensis	200-480	67	18.2	(11.7-23.7)	4	(2-8)
Pl. edwardsianus	320-900	44	27.2	(15.0-81.2)	16	(2-118)
C. granulatus	300-900	184	150.4	(114-179)	1,115	(500-2,020)

Table 2.—Summary comparison of shrimp and crab yields for different types of traps used. Abbreviations are as follows: kg/tp. = kilograms per trap; kg/tp.nt. = kilograms per trap night. Data include all shrimp species but mainly comprise *H. laevigatus*; the crab data are for *Chaceon granulatus*. Trap abbreviations: COMB, combined shrimp/crab trap, three-chambered STD; STD, standard box trap (2x1x1 m); PYM, pyramidal, top entry (1x2 m²); BOX, covered box (1.5x5x5 m); PAL, traditional Palauan fish-trap (1.5x1x1 m); CAA (1x1x1 m) trap on remote camera frame (1988 only); FLT, flat collapsible trap (60x40x20 cm).

Trap	Depth (m)	No. pulls	Shrimp Total	Shrimp kg/tp.	Shrimp kg/tp.nt	Crab Total	Crab kg/tp.	Crab kg/tp.nt.
COMB	480-800	13	18.89	1.45	0.79	66.21	5.09	2.76
STD	170-900	60	31.53	0.53	0.44	160.14	2.67	2.26
PYM	475-790	5	0.81	0.16	0.16	27.86	5.57	5.57
BOX	256-640	2	0.16	0.08	0.08			
FLT	300-580	3	0.41	0.10	0.08	9.81	2.45	1.96
PAL	352-800	9	1.24	0.18	0.14	2.68	0.38	0.30
CAA	464-704	6	2.00	0.33	0.50			



Figures 4a,b.—Frequency distributions showing (a) wet weights of *Heterocarpus laevigatus* (n=694, range 2-106 g, mean 41 g), and (b) *Heterocarpus ensifer* (n=163, range 2-22 g, mean 9 g).



Figures 5a,b.—Frequency distributions showing (a) proportions of male/female *H. laevigatus* according to carapace length, and (b) ovigerous/nonovigerous females according to carapace length in *H. laevigatus*.

pace length for the entire sample ranged from 6.5 to 35.9 mm ($\bar{X}$ 25.3 mm), and the two sexes were essentially the same size ($\bar{X}$ males 26.5 mm, and females 26.8 mm). Other shrimp species occasionally caught in substantial numbers included *Heterocarpus gibbosus* (24 to 42 g, ($\bar{X}$ = 34 g), *Plesionika ensis* (2-8 g, ($\bar{X}$ = 4 g), and *Plesiopenaeus edwardsianus* (2-118 g, ($\bar{X}$ = 16 g; Table 1).

The overall weight range for 184 individuals of *Chaceon granulatus* was 500-2,020 g ($\bar{X}$ = 1,115 g; Fig. 6), and maximum carapace width ranged from 114 to 179 mm ($\bar{X}$ = 150.4 mm). Males were substantially larger than females (male $\bar{X}$ = 1,219 g vs. female $\bar{X}$ = 976.9 g, and male carapace width $\bar{X}$ = 153.2 mm vs. female $\bar{X}$ = 146.7 mm). Males outnumbered females 107 to 80 (1:0.75). However, the proportion of females increased with depth, and the nine deepest traps (900 m) contained all females. Only 11 (13.8%) of the 80 females were ovigerous.

Photosequences

Perhaps the greatest advantage of a time-lapse photosequence sampling technique is that it provides a chronological record of bait site activity, including numbers and types of animals both in and around the trap, rather than just a record of what remains in the trap when it reaches the surface (Fig. 7, 8).

A total of 27 photosequences was obtained, including 22 in Mutremdiu Bay (Fig. 1), taken between 1979 and 1982 (additional details are provided by Saunders 1984), and five additional sequences were obtained in West Passage, in 1988. The 27 photosequences obtained spanned periods of 3.5-17 h, at depths of 73-700 m. *Heterocarpus ensifer* was present in 14 photosequences, *H. laevigatus* was present in seven, *H. laevigatus* and *H. ensifer* together were recorded in six, and *H. laevigatus* alone was recorded in one (Table 3).

Behavior and Activity

First appearance of the shrimps at baited camera sites (bait discovery

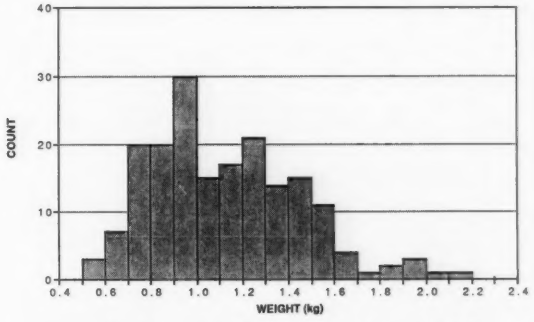


Figure 6.—Frequency distribution showing wet weights of *Chaceon granulatus* (n=184, range 0.5-2.02 kg, mean 1.11 kg).

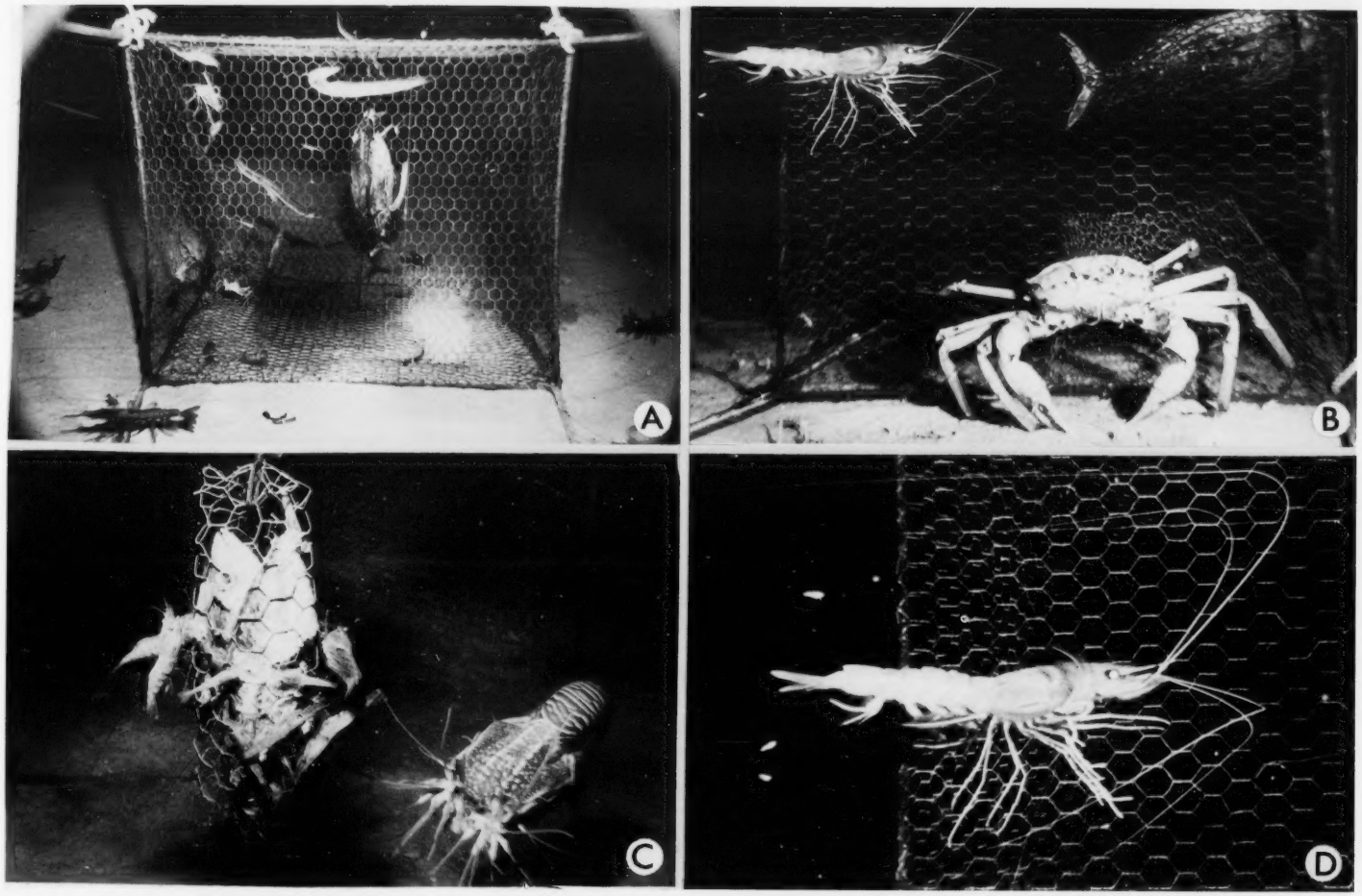


Figure 7.—Selected remote camera photographs taken at baited trap sites around Palau: A) *Heterocarpus laevigatus*, *Plesiopenaeus edwardsianus* and deep-water eels, 469 m, day set (seq. 18); B, D) *Chaceon granulatus* and *Plesiopenaeus edwardsianus*, 700 m, night set (seq. 27); and C) *Heterocarpus ensifer* and *Nautilus belauensis*, night set, 217 m (seq. 21). For scale, trap is 1 m across, mesh is 2.5 cm.

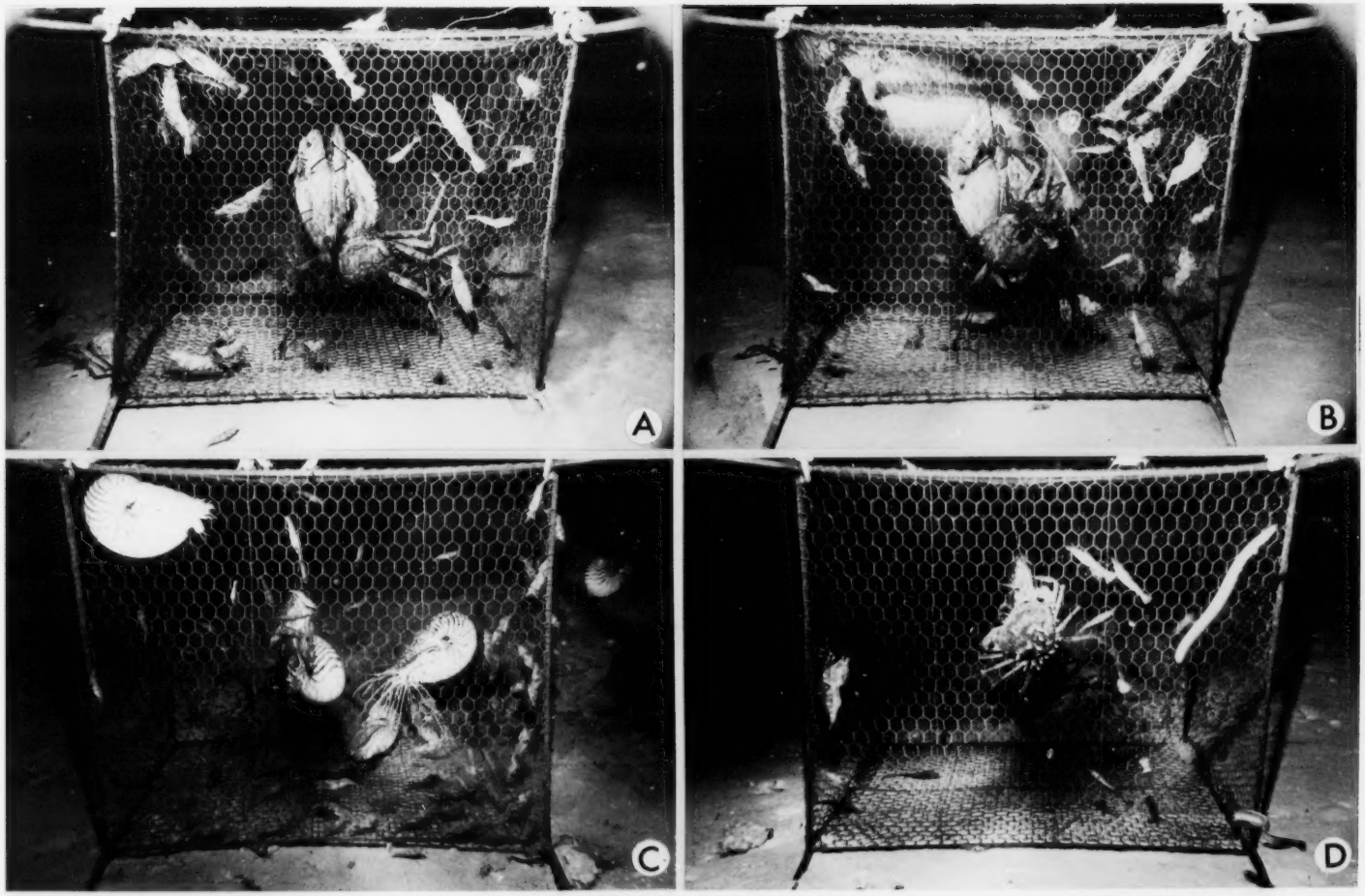


Figure 8.—Additional remote camera photographs from Palau: A) *Heterocarpus laevigatus, Plesiopenaeus edwardsianus, Chaceon granulatus,* and (in B) *Hexanchus griseus* (bluntnosed six-gill shark), 528 m, day set (seq. 20); C) *Nautilus belauensis* and swarm of *Heterocarpus ensifer,* day set, 284 m (seq. 7); D) *Heterocarpus laevigatus, H. ensifer,* and deep-water eels, 479 m, day set (seq. 6). Same scale as Figure 7.

Table 3.—Summary data for remote deep-water photosequences (arranged by increasing depth). Maximum number of *Heterocarpus laevigatus* (*H. laev.*) or *H. ensifer* (*H. ensif.*) observed in a single frame; B.T.=botom time in hours or span of photosequence on the bottom; N/D=whether primarily daylight or darkness; B.D.T.=bait discovery time or elapsed time in hours before first arrival of *H. laevigatus* or *H. ensifer*. Sequences 1-22 taken off Mutremdiu Point, Auguilpelu Reef; sequences 23-27 taken off West Passage.

Sequence	Depth (m)	H. laev.	H. ensif.	B.T. (h)	N/D	B.D.T. (h)
1. 14	73	0	0	1100-1620	D	
2. 10	95	0	0	900-1815	D	
3. 11	107	0	0	2015-0530	N	
4. 9	110	0	0	0915-1645	D	
5. 3	146	0	20	1500-0700	N	1.5
6. 13	146	0	0	0930-1730	D	
7. 12	146	0	0	1145-1530	D	
8. 22	191	0	28	1800-0300	N	0.75
9. 1	192	0	27	1830-1030	N	0[1]
10. 21	217	0	12	1745-0230	N	1.25
11. 15	238	0	100	2030-0630	N	0[1]
12. 2	238	0	0	0900-1700	D	
13. 4	274	0	4	1000-1630	D	3.5
14. 5	278	0	50	0730-1545	D	0[1]
15. 7	284	0	50	0800-1530	D	0[1]
16. 17	357	0	150	0930-1530	D	0[1]
17. 19	449	12	3	1830-0315	N	0[1]
18. 18	469	6	21	0930-1615	D	0[1]
19. 6	479	6	15	0930-1630	D	0[1]
20. 16	504	20	8	0900-1715	D	0.25
21. 20	528	26	14	0945-1630	D	0[1]
22. 8	538	29	0	1830-0430	N	0[1]
23. 23	512	4	0	1130-1300	D	0[1]
24. 24	550	6	2	1200-0530	D	0.25
25. 27	560	6	2	1700-0800	N	0.5
26. 25[2]	590	8	3	1630-1900	N	1.5
27. 26[2]	700	9	0	1630-2430	N	1.0

[1]Bait discovery times (BDT) of 0 indicate that shrimps were present in the first frame taken.
[2]Camera malfunction caused irregular photograph interval.

time) is essentially instantaneous, as shown by their presence in the first frame of almost every sequence taken at depths below 270 m (Table 3). Comparison of a series of individual photosequences provides evidence that the two species behave differently. The larger species, *H. laevigatus*, is drawn to the bait in slow but steadily increasing numbers, as shown in plots of the maximum number of shrimp recorded in a single photographic frame, against elapsed time (Fig. 9, 10). By contrast, *H. ensifer* behaves in a much more erratic fashion, with specimen counts fluctuating as much as 100% between successive photosequence frames (e.g., Fig. 10b). The records suggest that *H. ensifer* is gregarious, and possibly follows scent trails in swarms. Traps are observed containing well over 100 specimens of *H. ensifer* in several photosequences, but the shrimps seem to have no difficulty in moving in and out of the trap. By contrast, *Heterocarpus laevigatus* appears in fewer numbers and tends to be solitary. This species also seems less active, in that individuals are often seen to remain motionless for as long as several hours at a time—either on the sea bottom or, more often, on the sides of the trap.

Diurnal/Nocturnal Variations

Detailed analysis of data from Palau provides evidence of crepuscular influence on *Heterocarpus ensifer*, as follows:

1) In two shallower photosequences (146 m depth), no shrimps are recorded during daylight, but as many as 20/frame are present at night, appearing at about sunset, leaving the bait site as dawn approaches (Fig 11a).

2) In three sequences at 191-217 m depths, *Heterocarpus ensifer* appears en masse during the evening crepuscular period (1830-1900 h).

3) In two 238 m sequences, no shrimps are recorded during daytime sets, whereas more than 100/frame are present at this depth during a night sequence (Fig. 11a).

4) These crepuscular fluctuations in *H. ensifer* do not occur below about 270 m, and the deeper species, *H. laevigatus* (whose upper range is ~350 m), is not sensitive to crepuscular photic changes. Two daytime sets at 274 and 278 m show *H. ensifer* in the first frames at 0730 and 0930 h, and such

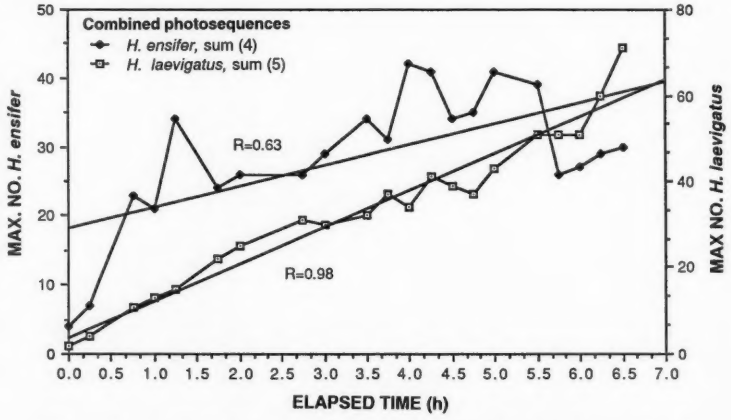


Figure 9.—Combined record of five photosequences showing the number of *Heterocarpus laevigatus* and four sequences showing *H. ensifer* visible in each photosequence frame, plotted against elapsed time (beginning with camera touchdown; see Table 3 for clock times). Note that the numbers of *H. laevigatus* in the field of view tend to gradually increase with time. By contrast, *H. ensifer* numbers may fluctuate widely, reflecting their tendency for erratic swarming behavior and for crepuscular migrations.

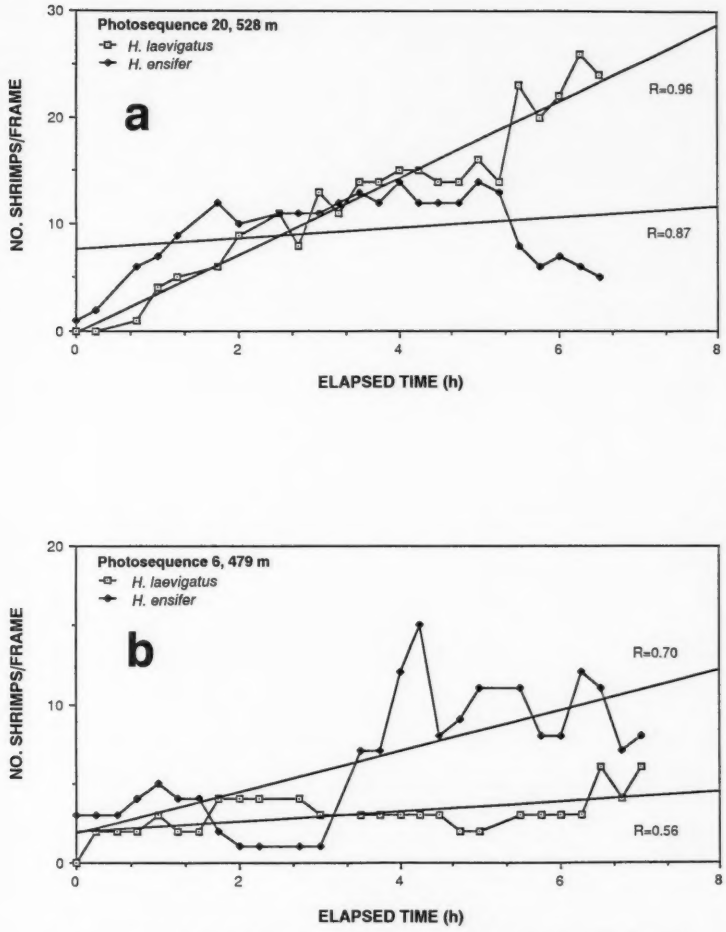


Figure 10a,b.—Individual photosequence records showing numbers of *Heterocarpus laevigatus* and *H. ensifer* visible in each photosequence frame, plotted against elapsed time (beginning with camera touchdown; see Table 3 for clock times). Note differences in behavior of the two species, reflected by difference in linear slopes, and fluctuations in numbers of individuals with time.

"on-arrival" appearances characterize all daytime sequences below 300 m (e.g., Fig. 11b, Table 3).

5) In all photosequences below 270 m, there appears to be no correlation between time of day and shrimp activity or numbers; there is, however, a good positive correlation between elapsed time and numbers of shrimps present.

Discussion

The combination three-chambered trap, with extended soak times of 48-72 h, consistently produced higher yields than more conventional designs such as are successfully used elsewhere (King, 1980, 1982, 1984; Struhsaker and Aasted, 1974; Gooding, 1984; Tagami and Barrows, 1988).

Of the 15 shrimp species caught during the Palau survey, only *H. laevigatus* (maximum weight = 106 g) was caught in sufficient quantities to qualify as a potential fishery resource. The same sex ratio was reported for this species in Hawaii by Dailey and Ralston (1986) who also recorded seasonal fluctuations in the proportion of ovigerous females. However, Moffitt and Polovina (1987) suggested that the depth of sampling effort may greatly influence the observed overall sex ratio. The size at maturity of female *H. laevigatus* (~40 mm carapace length) observed in Palau is similar to that reported for this species elsewhere (Dailey and Ralston, 1986; Moffitt and Polovina, 1987).

The smaller species, *H. ensifer*, was caught in low numbers and inconsistently. Substantially higher yields of the larger species were also recorded by Moffitt and Polovina (1987) in the Marianas. Of the other species recorded in Palau, *H. gibbosus*, *H. dorsalis*, and the penaeid species *Plesiopenaeus edwardsianus*, attained large sizes (maximum weights of 42 g, 32 g, and 118 g, respectively) although numbers were generally low. For marketing purposes, these species could be combined with *H. laevigatus*, but the other species obtained were too few or too small to be regarded as a marketable by-catch. King (1986) mentioned that *Nautilus* shells may represent a valuable by-catch for the tourist market in the Pacific islands. However, in Palau, *Nautilus* is protected, and is the type locality and only known occurrence of *N. belauensis* (Saunders, 1984).

Although the depth ranges of *Heterocarpus ensifer* and *H. laevigatus* overlap in Palau, they do not occur together in great numbers as reported elsewhere (e.g. King, 1986; Moffitt and Polovina, 1987). The Palau photosequences record *H. ensifer* between ~150 and 550 m, but it should be noted that the shallower occurrences (<250 m) are all nocturnal. Trap yields indicate a slightly narrower range for *H. ensifer*, ~200-350 m. *Heterocarpus laevigatus* is generally a deeper ranging species; the upper range in photosequences is 449 m (and this is not subject to diurnal fluctuations), but moderate trap yields were obtained as shallow as 375-400 m. Trapping results show that this species ranges as deep as 850 m, but the lower limit in Palau is not known. The combined evidence indicates the overlapping depth range of the two species is about 300-550 m.

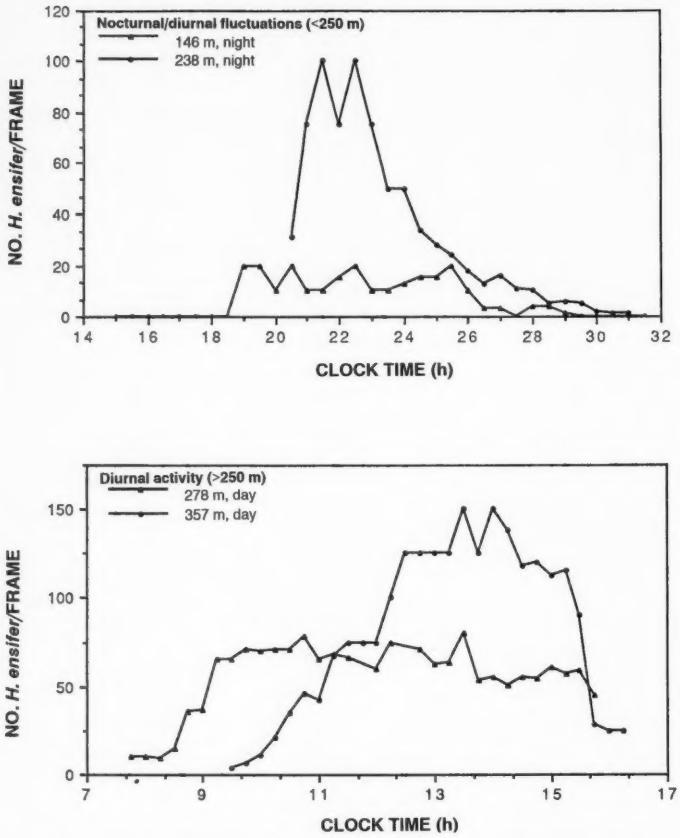


Figure 11a,b.—Records of four photosequences showing number of *Heterocarpus ensifer* per photosequence frame, plotted against clock time. Above 250 m (a), *H. ensifer* is present only during hours of darkness, arriving and departing during evening and morning crepuscular periods, respectively. Below ~250 m (b), *H. ensifer* is present and active during daylight as well as darkness, often occurring in swarms, with more than 150 individuals visible in a single frame.

The preferred depth ranges appear to be ~200-400 m for *H. ensifer*, and ~400-800 m for *H. laevigatus*.

Time-lapse remote camera photosequence records permit monitoring different species and even different individuals over a prolonged period. The counts of individuals observed in a single frame are probably underestimates of the numbers of individuals actually present in the field of view, because the bait or larger animals may obscure some smaller specimens. But the general consistency of specimen counts from one frame to the next suggests that this is an equitable estimate of what is present around the bait site.

The instantaneous appearance of shrimps at bait sites may mean that they can detect the scent trails of descending baited traps. This ability has previously been observed in the planktonic shrimp *Acetes* (Hamner and Hamner, 1977). As the records show, *Heterocarpus ensifer* tends to occur in erratic swarms, moving actively in and out of traps, whereas *H. laevigatus* tends to be more of a solitary animal, drawn in gradually increasing numbers to the bait over a longer period of time. Like *Nautilus* (Saunders, 1984), *H. ensifer* in its upper depth range seems to be affected by diurnal photic fluctuations; between depths of 150 and 270 m, it appears in large numbers during the evening crepuscular period and disappears at dawn. Essentially identical patterns of crepuscular movement have recently been reported in photosequences taken at 147-372 m depths off Manus, Papua New Guinea, with morning arrivals and evening crepuscular disappearances recorded in every sequence (Saunders, 1990). These fluctuations apparently reflect movement up and down the reef slope, for below 270 m this species is present at all times. The larger shrimp, *H. laevigatus*, and the geryonid *Chaceon granulatus* do not seem to be affected by nocturnal/diurnal photic fluctuations.

The photosequences indicate that the key to attracting shrimps and retaining them is scent. As long as bait is present, even if it is inaccessible (e.g., if enclosed in fine wire mesh bags), shrimps will linger in the vicinity whether or not they are actually feeding on bait. However, once the bait has been consumed (in many cases this is accelerated by copepods), the animals move about the trap until egress is attained. Trapping strategists would do well to keep these behavior modes in mind; not only is it necessary to attract the animal using scent sources, it is also necessary to maintain a scent presence to discourage escape. It may be that preventing or discouraging egress is a more important factor in trapping yields than attracting large numbers of animals to the bait. From this standpoint, spring-loaded door closure triggered by soluble magnesium links, timed to scent dimunition, might be a productive direction for future research efforts.

At present, little information is available regarding the life history and fishery potential of *Chaceon granulatus*, and only recently have data become available on geryonid crab fisheries in general (Melville-Smith, 1988; Lindberg and Wenner, 1990). A few details are now available concerning *C. fenneri* and *C. quinquedens* off the eastern United States and in the Gulf of Mexico (Wigley, et al., 1975;

Wenner, 1990; Lindberg, et al., 1990; Kendall, 1990; Armstrong, 1990; Hinsch, 1990) and considerably more information is available for *C. maritae* off southwest Africa (Melville-Smith, 1988; 1990). These sources indicate that observations reported here on *C. granulatus* in Palau are also generally true for other species of *Chaceon*, including sexual dimorphism, unequal sex ratios, and sex segregation by depth.

The present study indicates that there is potential for combined deepwater trapping of *Heterocarpus laevigatus* and *Chaceon granulatus*. This requires using large, three-chambered traps set for extended soak times (48-72 h), at depths of ~400-800 m. The forereef slopes of most western Pacific islands have only a limited number of sites with low-slope bottom conditions favorable for setting traps, but each of these could accomodate a few traps over an extended period, with replenishment of stocks generated from the extensive adjacent reef slopes that are too steep to trap. This is envisaged as a secondary undertaking by individual fishermen, to supplement ongoing fishing efforts. The economic feasibility of such an operation, based on the local infrastructure of Palau, is discussed in greater detail by Saunders et al. (1989). Similar small-scale deepwater trapping efforts should also be feasible in other oceanic archipelagoes in the Indo-Pacific. If properly managed, they could provide a supplementary source of income for local fishermen that should sustain itself indefinitely.

Acknowledgments

This study was supported by a Saltonstall-Kennedy Grant to the Pacific Fisheries Development Foundation, Honolulu, and the assistance of Carol Odo of that organization is acknowledged. Toshiro Paulis, Chief, Marine Resources Division, Palau, was the project coordinator, and Pablo Sianglideb, T. Remoket, M. Kotaro, T. Boisek and E. Ngotel assisted extensively. Gerald Heslinga, Micronesian Mariculture Demonstration Center, provided support. Staff members of the National Marine Fisheries Service, Honolulu Laboratory, including Robert Moffitt, Steve Ralston, Daryl Tagami, and Jeffrey Polovina, were particularly helpful. Raymond B. Manning, U.S. National Museum of Natural History, Washington, D.C., kindly assisted with crustacean identifications, and specimens have been deposited at the USNM and at the Bishop Museum, Honolulu. For additional details, see Saunders et al. (1989).

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On the Distribution and Fishery Potential of the Japanese Red Crab *Chaceon granulatus* in the Palauan Archipelago, Western Caroline Islands

L. C. HASTIE and W. B. SAUNDERS

Introduction

As the world demand for crustacean meat of all kinds continues to rise, interest has grown in the potential for commercial exploitation of deep-water geryonid crabs. These animals are widely distributed in the world's oceans, commonly occurring on continental slopes at depths of 100-2,000 m (Manning, 1990). Several members of the genus *Chaceon* (formerly *Geryon*[1]), typically medium to large crabs with high quality flesh, are considered marketable.

Presently, there are two major geryonid fisheries in the Atlantic. Off the northeastern United States is an established fishery for the red crab, *Chaceon quinquedens*, which has operated since the early 1970's (Armstrong, 1990). A similar species from west African waters, *C. maritae*, has also been significantly exploited (Melville-Smith, 1988). On information from FAO (1986) and Melville-Smith (1988), it can be estimated that the total world geryonid catch exceeded 12,000 t in 1981. Interest in these fisheries has resulted in exploratory surveys for several Atlantic species, including *C. affinis* (Shelton, 1979), *C. fenneri* (Wenner et al., 1987; Kendall, 1990; Lindberg et al., 1990; Wenner, 1990), *C. notialis* (Barea and Defeo, 1985; Defeo et al., 1991), and, in other areas, *C. quinquedens* (McElman and Elner, 1982) and *C. maritae* (Cayre et al., 1979).

There is an apparently similar, wide distribution of geryonid crabs in the tropical and subtropical Pacific (Sakai,1978; Cayre et al., 1979; King, 1984; Saunders, 1984; Hayasaka, 1985; Manning and Holthuis, 1989). Extensive exploratory deep-water trapping surveys have been undertaken in this region and are well documented (Struhsaker and Aasted, 1974; King, 1981, 1986; Gooding, 1984; Moffit and Polovina, 1987). However, these have tended to concentrate on the two caridean shrimp species, *Heterocarpus ensifer* and *H. laevigatus*.

A recent study of this nature by Saunders et al., (1989) revealed a population of the Japanese red crab, *Chaceon granulatus*, on the deep forereef slopes around Palau, Western Caroline Islands. Preliminary evidence suggests that it may be of sufficient density to support a local fishery. It is possible that similar populations of geryonids exist on the slopes of several Indo-Pacific archipelagoes. This paper is largely based on observations of *C. granulatus* made during red crab explorations in Palau. A brief review of the present status, distribution, and fishery potential of Pacific geryonids in general is included.

Procedures

A total of 103 traps was set between 170 m and 900 m depth at five stations around Palau (Fig. 1), between 1987 and 1988. Several trap designs were initially tested (Saunders et al., 1989). Quantitative samples were obtained by using a large box trap (2x1x1 m) with 25 cm diameter funnels at each end. About 1 kg of bait, usually frozen skipjack tuna, *Katsuwonus pelamis*, was wrapped in chicken wire and suspended in the cen-

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ABSTRACT—A deep-water trapping survey in the Palauan archipelago, Western Caroline Islands, has revealed an abundance of the Japanese red crab, Chaceon granulatus. *The recorded depth range (250-900 m) is similar to that of other geryonids, but the large numbers of females caught below 700 m is atypical. Mean yields in excess of 5 kg crabs plus 1 kg shrimp,* Heterocarpus laevigatus, *by-catch per trap-night were attainable at optimum depths.* Chaceon granulatus *is apparently a very large geryonid, with maximum weights of 2.02 kg and 1.51 kg recorded for male and female specimens, respectively. A range of body colors was observed: Orange-red shades appear to dominate the deeper waters (below 500 m) while yellow-tan colors are more abundant in the upper reaches.*

Preliminary evidence suggests that Chaceon granulatus *is highly marketable, and the infrastructure in Palau is such that crabs could either be marketed fresh locally or airfreighted to Japan as a quick-frozen product. The high post-trapping survival rates observed indicate that maintaining crabs in live-holding tanks may be a feasible option. The large catches and quality of deep-water crabs taken suggests that the Palauan population of* Chaceon granulatus *may be able to support a small-scale fishery. It is not yet known whether this population is unusually large or whether these findings typify the deep forereef fauna of the region.*

[1]The family geryonidae was revised by Manning and Holthuis (1989) to include three genera: *Geryon* (2 species), *Chaceon* (21 species), and *Zariquieyon* (1 species).

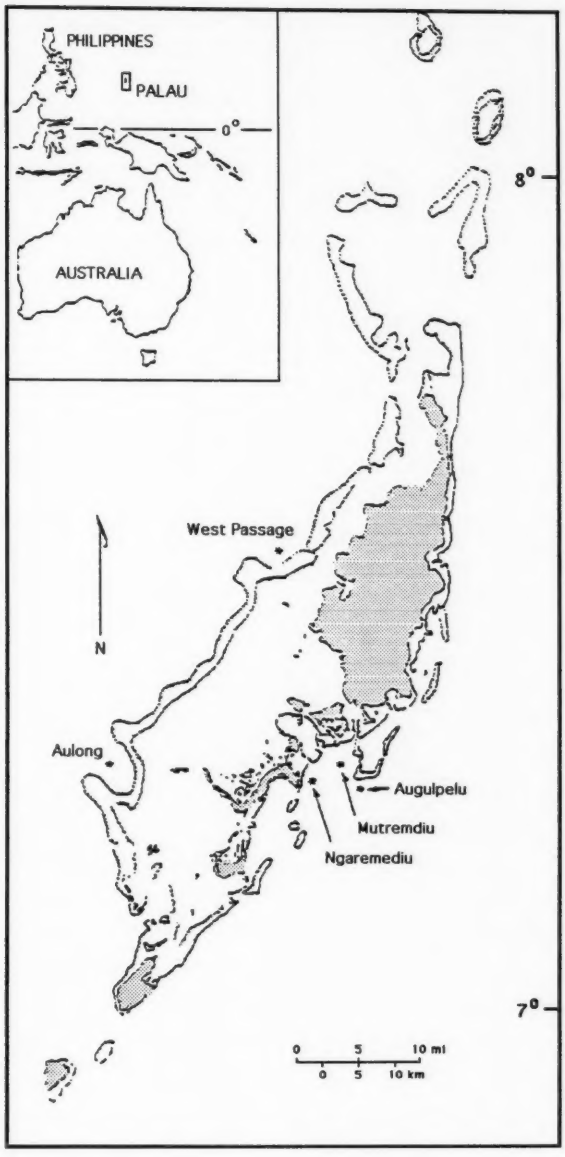

Figure 1.—Map showing deep-water trapping stations around Palau, Western Caroline Islands. Traps were set 103 times at 170-900 m, at 1) Mutremdiu Bay (38 sets), 2) Augulpelu Reef (7 sets), 3) Ngaremediu Reef (19 sets), 4) Aulong Bay (7 sets), and 5) Toagel Mlungui (West Passage) (32 sets).

ter of the trap; mesh baffles were included to impede egress (this design is referred to as the standard trap henceforth). Polypropylene rope (4-8 mm diameter) was used in conjunction with surface buoys and marker flags. Scrap-iron weights and anchors were attached to reduce trap dragging. Set traps were usually soaked overnight for 15-25 hours and pulled the following day.

The survey vessel was the MRD *Mesekiu*, a diesel 10 m Yanmar[2], equipped with a gasoline pot hauler. An Echotec CV950 VDU fathometer was available for depth determination. Catches, stored in a large ice cooler onboard, were later sorted in the laboratory. The crabs were sexed, weighed, and measured, and the shrimp by-catch data (species, number, weight) were also collected. All data were logged into a Macintosh Plus microcomputer using Cricket Statworks software.

[2]Mention of trade names or commercial firms does not imply endorsement by the National Marine Fisheries Service, NOAA.

Results

Distribution and Catch Rates

A total of 98 retrieved traps (5 were lost) yielded 238 red crabs (*C. granulatus*, 268 kg) and 1,550 shrimps (15 species, 55 kg). *Chaceon* was found over a considerable depth range (250-900 m, with corresponding water temperatures of 5-10°C (Fig. 2; Saunders et al., 1989)); the lower limit of the depth range was not established. Figure 3 shows the relative numbers of crabs caught at 50 m intervals. There is a marked increase below 650 m. The sex ratio recorded overall was 1.329:1 in favor of males, which were caught more frequently over most of their range (350-850 m). However, female crabs were more abundant in the deeper sets and tended to dominate catches from below 700 m. A few females were also caught in the shallowest sets (ca. 250 m), resulting in a greater depth range than that recorded for males. All the berried females were caught between 650 m and 770 m depth (Table 1).

In terms of catch per unit effort (CPUE), high yields (>5 kg per trap-night) were attained below 500 m (Fig. 2). Mean shrimp by-catches of around 1 kg per trap-night were also obtained between 600 and 700 m. These were dominated by the caridean *Heterocarpus laevigatus*, which composed 92% (51 kg) of the total shrimp yield by weight. A smaller species, *H. ensifer*, dominated the shallower catches of shrimp (170-400 m), but catch rates were generally poor (Fig. 2). Large numbers of the deep-water eel, *Synaphobranchus affinis*, were also taken, below 400 m.

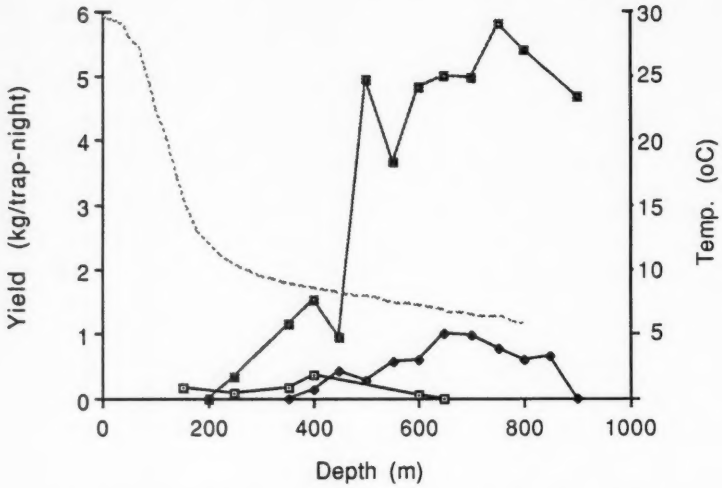

Figure 2.—CPUE values obtained for *Chaceon granulatus* (black squares) between 170 and 900 m depth. Shrimp by-catch values for *Heterocarpus laevigatus* (diamonds) and *H. ensifer* (white squares) are included. Based on standard trap data. The broken line represents a water temperature profile for Palau (May-October 1987), based on average readings from four trap sites (Saunders et al., 1989).

Physical Characteristics

Figure 4 shows the relative wet weights of male and nonovigerous female crabs examined. On average, males are larger and heavier than females (Table 1). Significant differences ($P<0.01$) in size and body weight were detectable (Student's t test). The relationships between carapace width and body weight were also tested, showing significant correlations ($P<0.01$) in both sexes (Fig. 5).

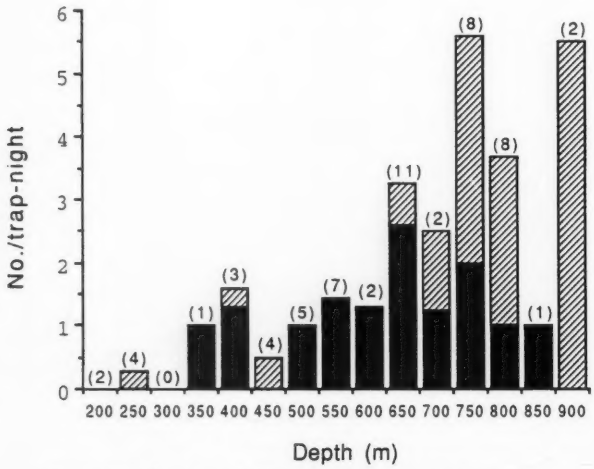

Figure 3.—Numbers of *Chaceon granulatus* caught at 50 m depth intervals, based on standard trap data. Male and female crabs are represented by black and hatched columns respectively. Effort (trap-nights) is shown in parentheses.

Observed body colors ranged from light yellow to deep red. Differences between sexes were not detected (Table 2). However, orange-red shades appear to dominate the deep waters (below 500 m), while yellow-tan colored animals are more abundant in the upper reaches (Table 3). Most individuals were uniformly colored, although a few dark red specimens had black patches on the carapace, claws, and legs. Darker crabs also tended to have harder, worn shells and frequently exhibited heavy barnacle settlement.

Marketability

Yields of quality white meat were easily extracted from the claws, legs, and bodies of a number of fresh crabs which had been steam-cooked. This was found to be palatable and similar in texture and flavor to that of lobster, *Homarus* sp. Some brown meat, also found in the bodies, was of poor quality.

A high percentage of crabs appeared to survive trapping operations. A sample of 43 hauled crabs were examined after 30 minutes on ice, and recorded as dead or alive, depending on any signs of movement in the claws, legs and oral region; only 7 remained moribund after 1 hour, representing a rapid revival rate of 84%. Two healthy animals were later maintained in refrigerated seawater (4°C) for 1 week.

Discussion

Chaceon granulatus has previously been recorded in the Western Pacific, as far south as Japan (Sakai, 1978). There it is considered to be quite rare and thus unsuitable for commercial exploitation (Tomiyama, 1983). The catches taken in Palauan waters are

Table 1.—Summarized size and weight data recorded for *Chaceon granulatus* specimens.

		Carapace width (mm)			Weight (kg)		
Sex	No.	Mean	S.D.	Range	Mean	S.D.	Range
Male	105	153.2	12.401	124-179	1.219	0.329	0.58-2.02
Female[1]	68	146.6	11.472	114-174	0.963	0.224	0.50-1.51
Female[2]	11	147.6	10.782	134-170	1.061	0.208	0.73-1.46

[1]Nonovigerous.
[2]Ovigerous.

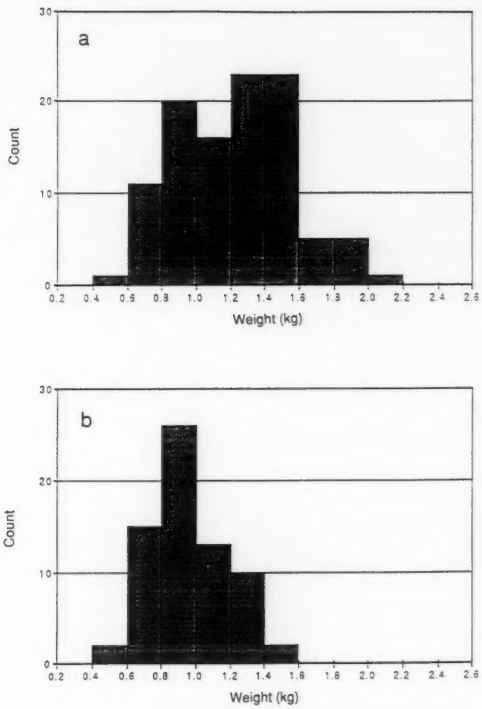

Figure 4.—Histograms of wet weights recorded for a) male and b) nonovigerous female crabs captured during the survey.

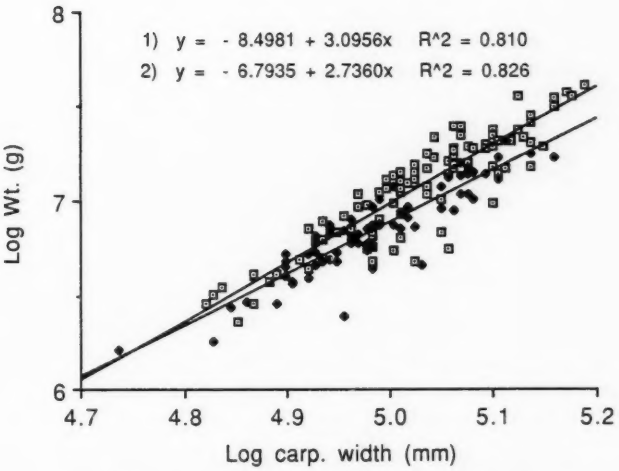

Figure 5.—Bivariate size (carapace width)-weight scatterplots for 1) male and 2) nonovigerous female crabs. Corresponding regression lines and correlation coefficients are displayed.

Table 2.—Observed body colors (carapace, claws, legs) of 51 *Chaceon granulatus* specimens caught at stations 4 and 5.

Color	No.	% of Males	% of Females
Orange-red	31	60% (24)	64% (7)
Dark red	9	18% (7)	18% (2)
Yellow-tan	10	20% (8)	18% (2)
Brown	1	2% (1)	0% (0)

similar to those reported for *C. quinquedens* (Gray,1970; Meade and Gray, 1973; Haefner and Musick, 1974; McElman and Elner, 1982) and *C. maritae* (Cayre et al, 1979; Melville-Smith, 1986), as well as other species under economic consideration in certain areas (Wenner et al., 1987; Defeo et al., 1991).

Although the lower depth limit was not established, the observed depth range of *Chaceon granulatus* (240-900 m) appears to be geryonid-typical. Sexual zonation has been frequently reported for geryonids (Haefner and Musick,1974; Wigley et al., 1975; Cayre et al., 1979; Beyers and Wilke, 1980; McElman and Elner, 1982; Barea and Defeo, 1985; Melville-Smith, 1988), with most workers concluding that females are typically more abundant at shallower depths. However, our findings suggest that, within the population of *Chaceon granulatus* around Palau, the reverse may be the case. A few *C. fenneri* females trapped by Wenner et al. (1987) in the South Atlantic Bight were deeper than most of the males, suggesting that sexual zonation may depend on several factors, such as species, water temperatures, seasonal effects, and spawning migrations.

Overall sex ratios in favor of males have been reported in trapping surveys for *C. quinquedens* (Gray, 1970; Haefner and Musick, 1974; McElman and Elner, 1982), *C. maritae* (Melville-Smith, 1988), *C. fenneri* (Wenner et al., 1987), and *C. notialis* (Defeo et al., 1991). To an extent, trapping may

Table 3.—Percent of observed body colors (pooled sexes) of *Chaceon granulatus* recorded at different depth intervals.

		<500 m		500-700 m		>700 m	
Color	No.	%	No.	%	No.	%	No.
Orange-red	31	25%	(2)	60%	(18)	85%	(11)
Dark red	9	25%	(2)	17%	(5)	15%	(2)
Yellow-tan	10	50%	(4)	20%	(6)	0%	(0)
Brown	1	0%	(0)	3%	(1)	0%	(0)

be sex-selective, in that female crabs carrying ripe eggs may not be attracted to bait; the possible exclusion of larger males due to funnel diameter restrictions should also be considered. Haefner and Musick (1974) observed a predominance of female *C. quinquedens* in trawls at shallower depths, while Melville-Smith (1988) has reported that *C. maritae* females are sometimes more abundant at certain depths and localities. The larger number of male crabs caught during this survey may have been influenced by the trapping effort, which was concentrated between 500 m and 750 m depth (Fig. 3).

According to records (Shroeder, 1959; McRae, 1961; Kjennerud, 1967; Mason and Davidson, 1969; Haefner and Musick, 1974; Sakai, 1978; Cayre et al., 1979; McElman and Elner, 1982; Barea and Defeo, 1985; Wenner et al., 1987; Manning and Holthuis, 1989), *C. granulatus* appears to be similar in size and weight to *C. affinis*, *C. bicolor*, and *C. fenneri*, and considerably larger than *C. quinquedens*, *C. maritae*, and *C. notialis*. Larger attainable sizes of male geryonids have previously been reported for all the aforementioned species (Schroeder, 1959; McRae, 1961; Sakai, 1978; Cayre et al., 1979; Shelton, 1979; McElman and Elner, 1982; Barea and Defeo, 1985; Wenner et al., 1987), and so *C. granulatus* appears typical in this respect.

Presently, there is debate as to whether body coloration is useful in distinguishing geryonid species (Manning and Holthuis, 1989; Manning, 1990), or whether it is too variable within certain species to be used as a taxonomic character (Hines, 1990). Our findings support the latter view, at least for *C. granulatus*. Manning (1990) has noted that red geryonid species are often found in deeper water than tan ones; this tendency has now been recorded intraspecifically for *C. granulatus*.

Preliminary evidence suggests that *C. granulatus* is highly marketable. Handling and processing techniques for geryonids are well documented (McRae, 1961; Haefner and Musick, 1974; Meade and Gray, 1973; Cayre et al., 1979; Melville-Smith, 1988). The present infrastructure in Palau is such that crabs could either be marketed fresh locally or as a quick-frozen product airfreighted to Japan (Y. Akiba, Nippa Fishing Corporation, Tokyo, personal commun.). The caridean shrimp by-catches are also valuable and could be marketed similarly. These options could be assessed in an economic feasibility study, based on extensive CPUE data. Given the high post-trapping survival rates observed, a further option might be to maintain crabs in live-holding tanks.

The catches and quality of deep-water crabs taken indicate that the Palauan population of *C. granulatus* may be able to support a small-scale fishery. It is not known, presently, whether this population is unusually large or whether these findings typify the deep fore-reef fauna of the region. Certainly, this species and its close congener, *C. bicolor* have been recorded in several Pacific localities (Fig. 6; Sakai, 1978; Cayre et al., 1979; King, 1984; Hayasaka, 1985; Manning and Holthuis, 1989).

Geryonid crabs are typically slow growing (Lux et al., 1982; Van Heukelem et al., 1983; Melville-Smith, 1989), and major recruitment events are thought to occur very rarely (Hines, 1990). Deep-water communities in general are particularly vulnerable to overfishing (Ralston, 1986), and the protection of these resources by strict management regimes will be crucial, particularly in Palau and other similar Indo-Pacific archipelagoes. Although these deep-water crab stocks are likely to be small and restricted in comparison to those on the continental slopes, they should be easier to define and hence manage effectively. Biomass estimates of several geryonid stocks have been calculated by various techniques, including trapping (Cayre et al., 1979; Defeo et al., 1991), trawling (Beyers and Wilke, 1980), effective area fished (EFA) (McElman and Elner, 1982; Melville-Smith, 1986; Defeo et al., 1991), and photography (Wigley et al., 1975; Melville-Smith, 1983, 1985). Individual archipelagoes in the Western Pacific possess relatively small areas at suitable depths for geryonid exploitation. Collectively, however, this area must be considerable.

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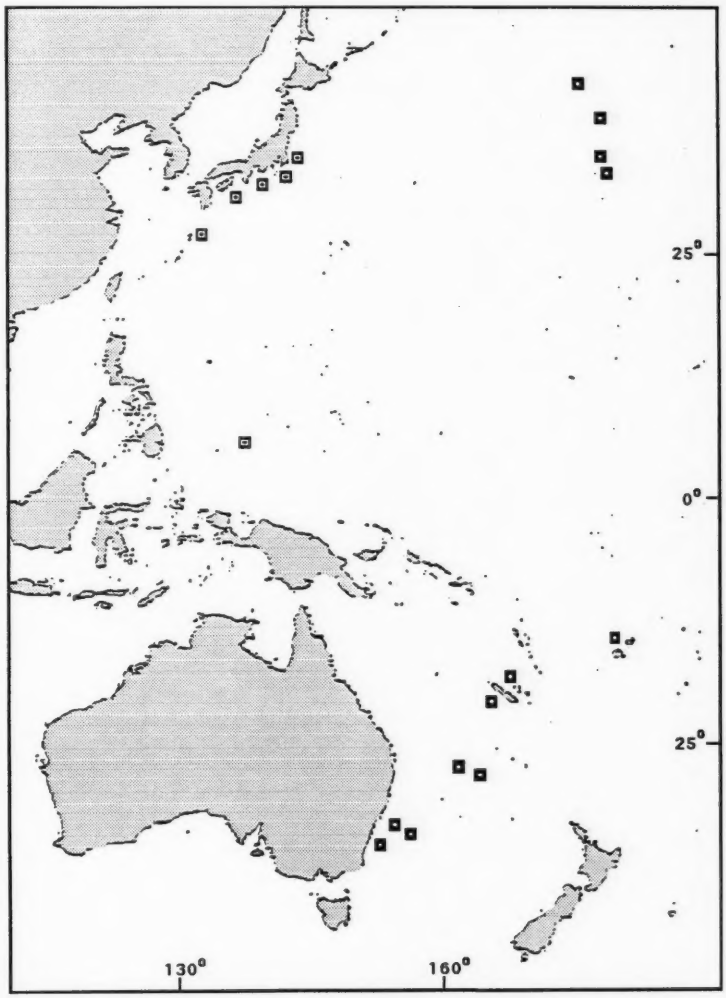

Figure 6.—Distribution of *Chaceon granulatus* (white squares) and *C. bicolor* (black squares) in the Western Pacific Ocean, based on the records of Sakai (1978), Cayre et al. (1979), Hayasaka (1985), Manning and Holthuis (1989), and Saunders et al. (1989).

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